CHAPTER 3

STEAM HEATING

Section I. DESCRIPTION OF EQUIPMENT

3-1. Steam and Steam Heating Systems

a. Properties of Steam. Steam is vaporized water. Steam carrying water particles in suspension is called wet steam. Steam without liquid water is called dry steam. Steam is a convenient medium for heat distribution because it carries a lot of heat in a small volume making possible the use of a small pipe. The process of evaporation of water in the boiler followed by condensation of steam in the radiators creates pressure differences which provide the motive power to distribute the steam throughout the heating system. Steam is used successfully for space heating at a wide range of pressure, from 150 psi gage down to a vacuum of over 10 psi gage. Systems classified as low-pressure commonly operate at pressures of a few psi gage. Systems operating at pressures in excess of 15 psi gage are termed high-pressure systems and commonly operate at pressures from 30 to 150 psi above atmospheric pressure. Systems operating at less than atmospheric pressure are called subatmospheric systems, vapor systems, or, if they employ a vacuum pump, vacuum systems. Significant properties of saturated steam at representative pressures are given in table 3-1. When saturated steam is supplied to a radiator, the useful heat comes almost entirely from condensation of the steam. The amount of this heat of condensation, or latent heat, is shown in table 3-1. For example, at atmospheic pressure, 14.7 psi (0 psi gage) a pond of dry saturated steam in condensing gives up 970.3 B.t.u. This latent heat per pound of steam does not change greatly over the pressure range employed in heating systems, although it does increase as the pressure decreases. However, low-pressure steam is also low-temperature steam and as the heat given off by a radiator to the surrounding air depends primarily on the temperature difference between the radiator and the air, low-pressure steam transmits less heat in a given time through a given radiator surface than would high-pressure steam through the same surface. The volume occupied by a pound of low-pressure steam is greater than that occupied by a pound of high-pressure steam; so a low-pressure system, in addition to requiring greater surface in the radiator, also requires larger pipe sizes than a high-pressure system of the same heating capacity.

Table 3-1. Properties of Saturated Steam

Pressure psi gage	Temperature ° F.	Latent heat Btu/lb	Specific volume cu ft/lb
−10	159.5	1,002.2	78.2
0	212	970.3	26.8
2	218.5	966.0	24.3
15	249.8	945.4	13.8
30	274.0	928.5	9.4
150	365.9	856.7	2.7

b. Steam Heating Systems. A steam heating system consists basically of a boiler in which heat from the combustion of fuel boils water to generate steam, radiators in which the steam is condensed giving up heat to the spaces to be heated, connecting piping to carry the steam from the boiler to the radiators and to return the condensate to the boiler, and an air valve or other means of eliminating air from the system. One type of steam system is shown in figure 3-1. There are many methods of arranging these basic items, and in some cases auxiliary equipment is used, as will be discussed in following paragraphs. In all cases the fundamental problems are getting the steam from the boiler to the radiators, returning the condensate to the boiler, and getting rid of the air.

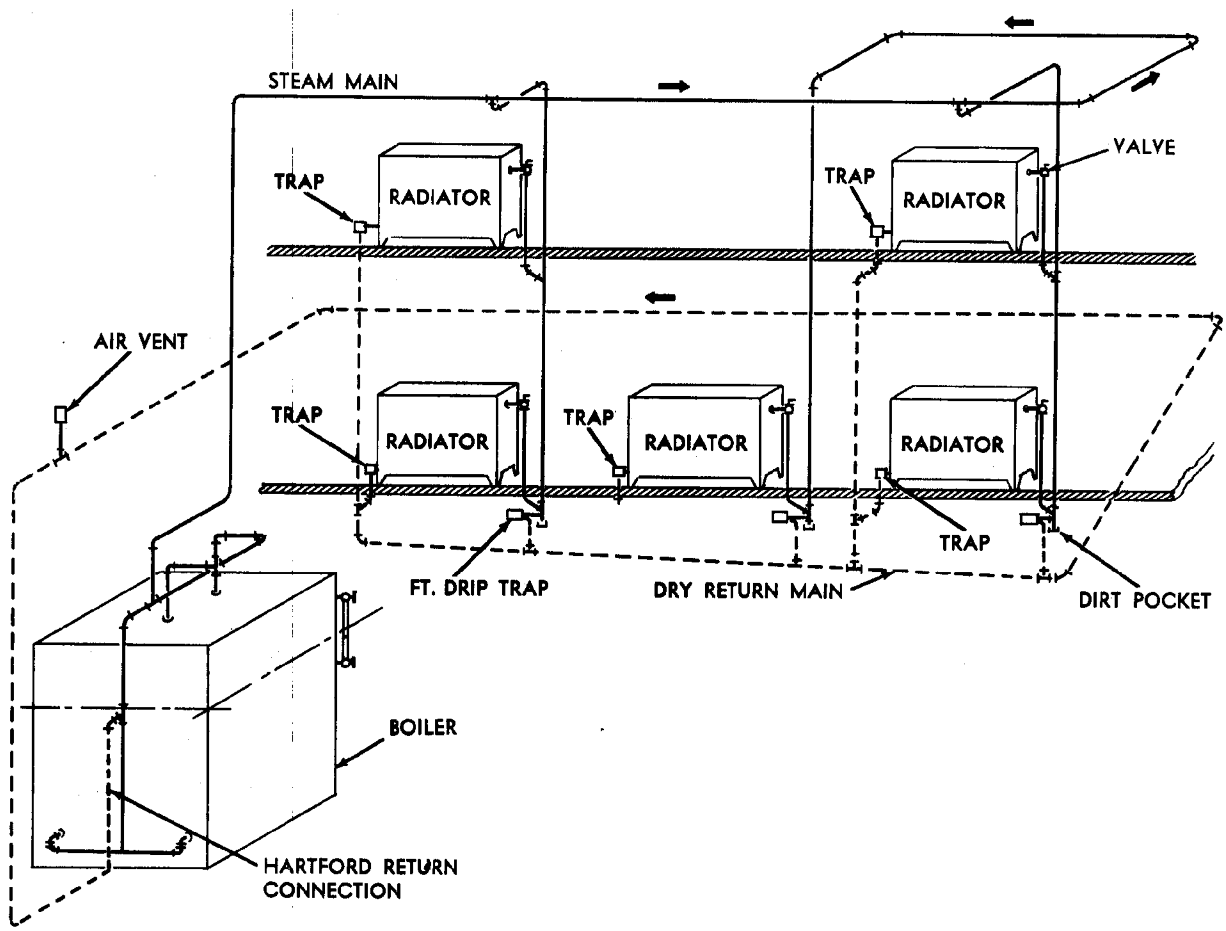


Figure 3-1. Two-pipe steam system.

3-2. Steam Boilers

a. Boiler Types. Heating boilers are made of either cast iron or steel. Steel boilers may be further classified as being either fire tube or water tube. Boilers may be designed to burn either coal, oil, gas, or all three. Boilers designed for coal can also burn either oil or gas at the rated boiler capacity. Boilers designed to burn oil can also be fired with gas. Boilers designed to burn gas have the smallest combustion space of all, and cannot be fired with any other fuel at the rated capacity of the boiler. All boilers are designed so that a grate can be installed to burn solid fuel in an emergency. Steam boilers should never be completely filled with water. A steaming space is required above the water level in the boiler to permit the vapor to separate from the water. Because steam heating systems are seldom completely tight, steam boilers require the frequent admission of fresh water to replace the water lost as steam. The boilers are provided with gage glasses and preferably also trycocks to check the water level. A safety valve must be provided. Unless the water used is exceptionally pure, or special methods are taken to treat it chemically, makeup water brings a supply of salts in solution into the boiler. These salts are eventually deposited on the boiler heating surfaces as water is evaporated. This forms a hard insulating scale which should be removed by the operator at regular intervals. Otherwise the heat transfer efficiency may be seriously reduced. Scale can be removed by manual scraping and chemical treatment. For detailed information, see TM 5-650.

(1) *Cast iron boilers.* Cast iron boilers are assembled in sections and are classified as either rectangular with vertical sections and rectangular grates (fig. 3-2) or round with horizontal ("pancake") sections and circular grates. These boilers are usually shipped in sections and assembled at the place of installation with push nipples and tie rods. They can usually be increased in size by the addition of sections. Some of the smaller sized cast iron boilers have water-filled spaces completely surrounding the combustion chamber. This "wet base" construction provides additional heating surface and makes it possible to install the boilder directly on a wooden floor. Round cast iron boilers are limited in size to about 1,500 square feet of steam radiation, but rectangular boilers may be obtained in much larger sizes. Cast iron boilers are normally limited to 15 psi steam pressure.

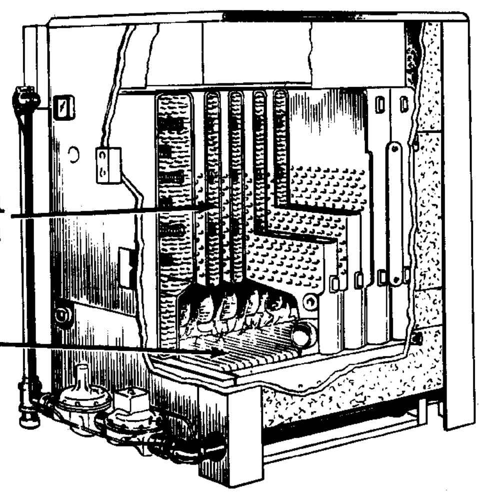


Figure 3-2. Cast iron sectional boiler.

(2) *Steel fire-tube boilers.* Steel boilers in which the gases of combustion pass through tubes and the boiler water circulates around the tubes are termed fire-tube boilers. Fire-tube boilers of small and medium size usually have a metal-walled combustion chamber (fig. 3-3. Because of their ease of installation they are the most popular type of steel boilers for low-pressure low-capacity purposes. A "fire-box" boiler requires no masonry setting except possibly an ash pit. Combustion gases travel from the fire box through tubes in the tank to a smoke box at the rear and then return through a second set of tubes to the flue connection at the front of the boiler from which they are discharged to the breaching or smoke pipe. Other types of fire-tube boilers vary in the number of flue passes, and some types require the construction of a complete masonry furnace and combustion chamber. For information on these larger boilers see TM 5-650.

(3) *Steel water-tube boilers.* Steel boilers in which water circulates inside tubes located in the path of flue gases are termed watertube boilers. As the design of these boilers avoids the use of large flat steam-containing surfaces, they can be designed for use at high pressures with safety. They have the further avdantage of being easier to clean than fire-tube boilers. However, as they require much masonry construction at the time of installation, they are more expensive than fire-tube boilers and are seldom used in any but the larger sizes. For further information see TM 5-650.

b. Capacity Ratings. Practically all heating boilers are now rated by one or more nationally accepted codes. Steel boilers are rated by the Steel Boiler Institute code (SBI). Cast iron boilers are rated by the code of the Institute of Boiler and Radiator Manufacturers (IBR) (table G-1). In addition, gas-fired boilers are rated by the code of the American Gas Association (AGA). Each of these codes prescribes a maximum recommended boiler load from standard test procedures and considerations of operating efficiency and boiler life. These ratings are available from boiler manufacturers and in publications of the associations named. Boilers may be rated as to capacity in terms of net load, design load, or gross load, and it is necessary to know the basis of a boiler rating before it can be applied properly. Net load is defined as the sum of the radiation load and the heat required to heat water for domestic use, along with the load of any other heating service which the boiler is expected to perform. The design load is the sum of the net load plus piping losses, as shown in table G-1. The gross load or maximum load is the sum of the design

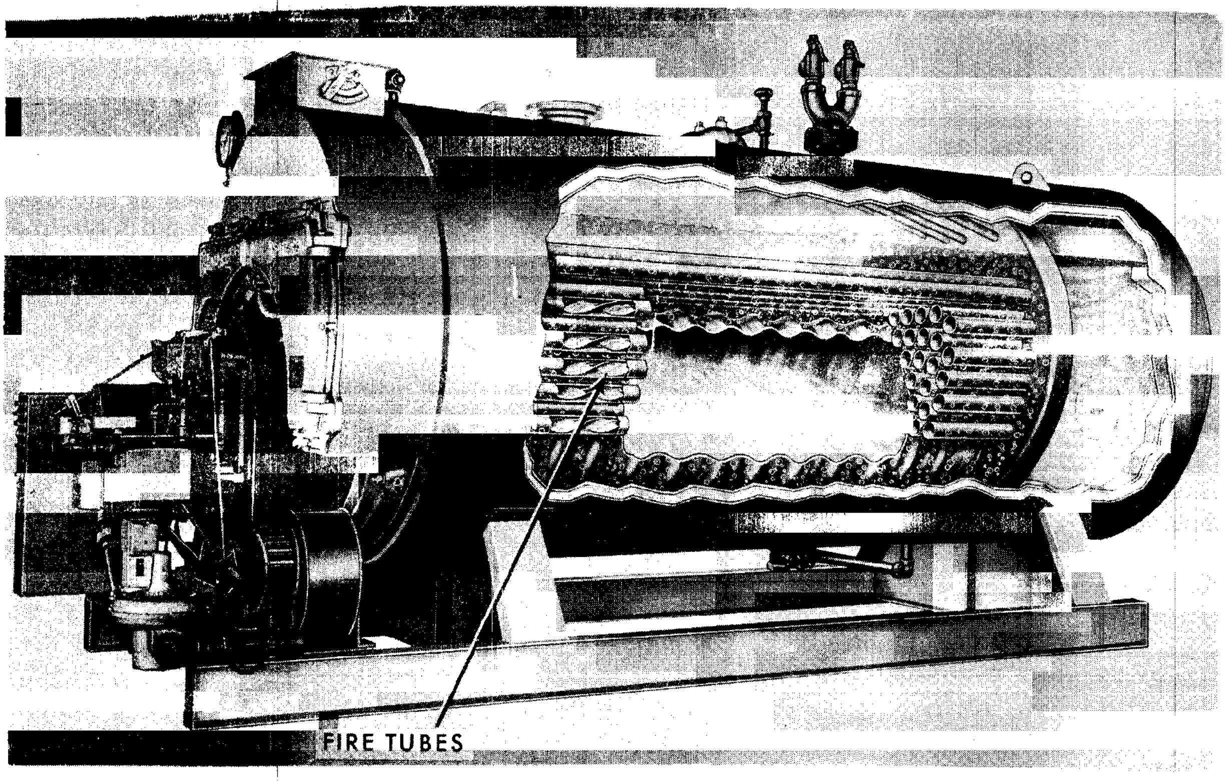


Figure 3-3. Cutaway view of horizontal fire-tube steam boiler.

load and an allowance for pickup, as shown in table G-1.

3-3. Radiators, Convectors, and Unit Heaters

a. Description. Heating of the spaces served by a steam heating system is accomplished by heat transfer elements generally classified as radiators, convectors, and unit heaters. The term radiator refers to a unit which emits a large part of its heat by radiation and includes cast iron radiators (fig. 3-4), and pipe coils. Actually a free-standing radiator emits approximately half of its heat by convection, and the fact that warm air currents rise vertically from the top of a radiator is an important consideration in selecting its location. Heat transfer elements shielded from the heated space so that all of the heat transfer is by convection are termed convectors (fig. 3-5). They may be made of cast iron or of finned tubing. The quantity of air passing over the convector and the resultant heat output are determined by the height of the warm air column from the bottom of the convector to the top of the discharge grill. Convector cabinets must therefore be installed or designed in accordance with manufacturers' instructions if rated output is to be obtained. A finned heat transfer surface, backed up by a fan to create forced air circulation through it, is termed a unit heater. Two types are shown in figure 3-6. Unit heaters are particularly helpful where large spaces are to be heated and it is desired to blow large quantities of warm air from a few sources located above head level. Although each of these methods of heat transfer is satisfactory when properly used, care should be taken not to use any two of them together on the same job unless their heat output is separately controlled. This is necessary because of differences in heat storage capacity for the same heat output. A cast iron radiator, for example, has a far greater heat storage capacity than a copper finned convector of equivalent output. In a heating system using both cast iron radiators and copper finned convectors controlled from a single thermostat, the radiators will continue

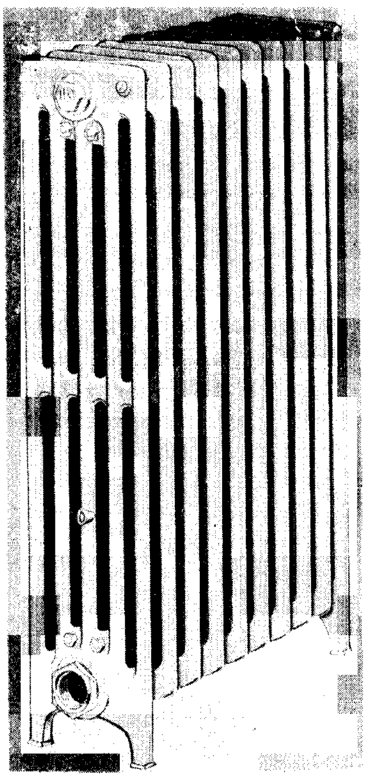


Figure 3-4. Radiator.

to heat long after the steam in the convectors has been condensed and the convectors and the spaces they serve are cold.

b. Ratings. Radiators were formerly rated by measuring the surface exposed, using a square foot of area as a unit of size. This unit, a square foot of radiation, was later standardized as the equivalent of 240 B.t.u. per hour for low-pressure steam radiators or 150 B.t.u. per hour for hot-water radiators. As thus defined the unit continues in use today, although there is a growing practice of rating these heating units in thousands of B.t.u. per hour, (MBH), output. Appendix H gives output rating for all sizes of radiators in common use. Ratings of column and large-tube radiators, no longer manufactured, are given in tables H-1 and H-2. Small-tube radiators with a spacing of approximately 1¾ inches per section are the only cast iron free-standing radiators now being made. Output ratings for these radiators are given in table H-3. Ratings for rectangular cast iron wall radiators are given in table H-4. Several manufacturers now make "baseboard radiation", long low units made to resemble conventional baseboards and installed along the outside walls of the rooms. They may be made of cast iron or of finned tubing installed behind a metal enclosure. Designs vary widely, and each make is rated differently. Radiators may also be made up of steel pipe running serpentine fashion along a wall. Table H-5 gives heat output rates for such type coils. Although methods have been established for the rating of convectors, convector design and dimensions vary so widely that each make must be separately rated, and reference should be made to manufacturer's specifications. A square foot of radiation is by definition equivalent to 240 B.t.u.'s per hour when the radiator is in a room temperature of 70°F. and the temperature of the heating medium of 215°F. When the temperature of the room or of the heating medium is appreciably different from these figures, determine the amount of radiation required through the use of heat emission factors given in table H-6.

3-4. Air Vents

As water at normal temperature usually contains some air which separates when the water is heated, means must be provided for removing this air from steam systems. Air must be removed from pipes and radiators before the steam can enter. Air is removed from one-pipe systems (para 3-14) by means of automatic air-release valves on radiators and mains, as shown in figures 3-7 and 3-8. These valves are operated by an internal thermostatic element and float. In the type shown, the thermostatic element consists of a bellows containing a volatile liquid. When steam pressure in the system increase above the pressure of the atmosphere, any air present is forced out through the venting port. When the relatively cool air has escaped and hot steam enters the valve, the liquid in the bellows expands forcing the upper ball shutoff down to close off the venting port, preventing the further escape of steam. If for any reason water tends to escape through the valve, the lower ball float rises to close off the port and prevent the escape of water. The most desirable types have in addition a small check

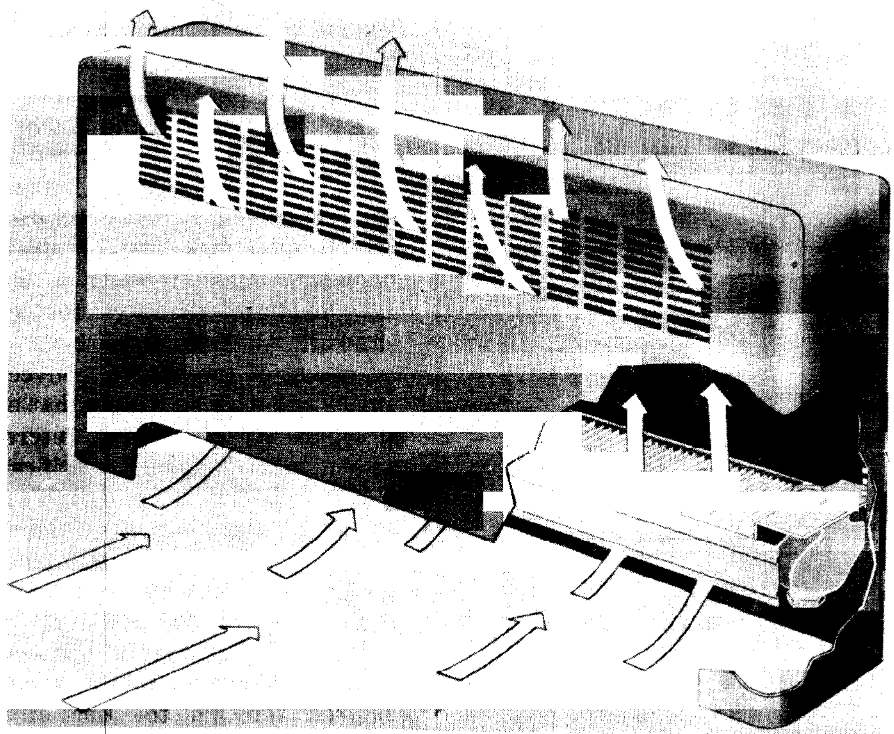


Figure 3-5. Convector.

valve which closes to prevent the readmission of air when pressure within the system begins to fall. This vacuum type air valve serves to keep the radiators warm for some time after the fire in the boiler has been allowed to die down. This occurs because the temperature at which water boils lowers as the absolute pressure decrease, and vapor at 160°F. or even lower will circulate throughout the heating system if air can be prevented from entering and the pressure falls below atmospheric. A further improvement in radiator valves is the use of a manually adjustable air escape orifice. Adjustment of the size of this orifice controls the rate at which air is vented from the radiator and in turn the rate at which the radiator heats up. Radiators which heat more rapidly than the average for the system can thus be retarded so that the entire system heats evenly. These are particularly effective when the system is under automatic control and the heat input cycles frequently. In addition to the vent valves on radiators, similar but larger valves are advisable for the ends of steam supply mains. These valves permit the entire main to be freed of air quickly so that steam will reach the radiators connected to the far end of the main almost as soon as it reaches those nearest the boiler. In two-pipe steam systems (para 3-15), air leaves the radiator along with the condensate, passing through a steam trap (para 3-5) into the return piping system. All air is then collected and removed by an air eliminator (fig. 3-9) at a central point.

3-5. Steam Traps

a. Function. A steam trap installed in the steam piping system is an automatic valve which opens to allow the passage of air or water but closes to prevent the passage of steam. Traps are installed in two-pipe systems at the outlet connections of radiators or other steam-operated apparatus to keep the apparatus full of steam while permitting the passage of air and condensate. They are also used to aid the flow of steam by removing conden-

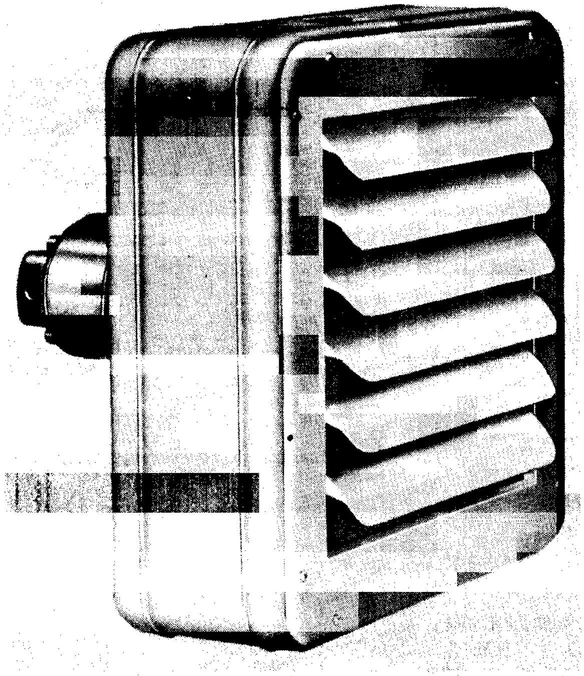


Figure 3-6. Unit heaters.

sate and air from steam piping. They can only be used in systems employing separate return piping.

b. Types. Traps may be operated by thermostatic elements, floats, or by the action of condensate at high pressure flashing into steam at a lower pressure. For a complete coverage of the various types of traps available, see TM 5-652.

3-6. Steam Valves

a. Function. Valves may be used to regulate the rate of steam flow, to stop the flow altogether, to permit flow in one direction only, or to regulate steam pressure. They may be manually or automatically operated. Valves are installed at the inlet and sometimes at the outlet of radiators and other steam-consuming apparatus to control operation. Release valves are installed on boilers and pressure vessels to protect them from dangerous pressure. Pressure regulators are used when high-pressure steam is supplied and lower pressure steam is required for space heating, water heating, or other services.

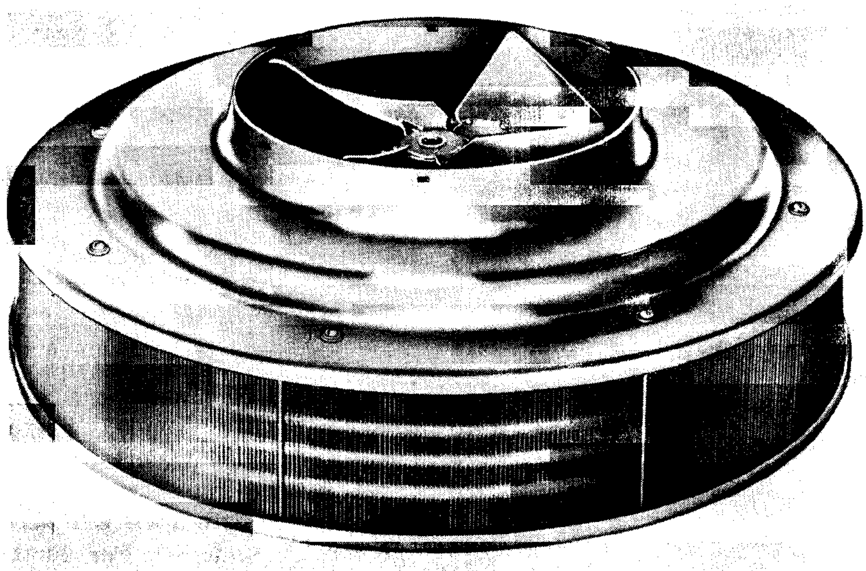


Figure 3-6—Continued.

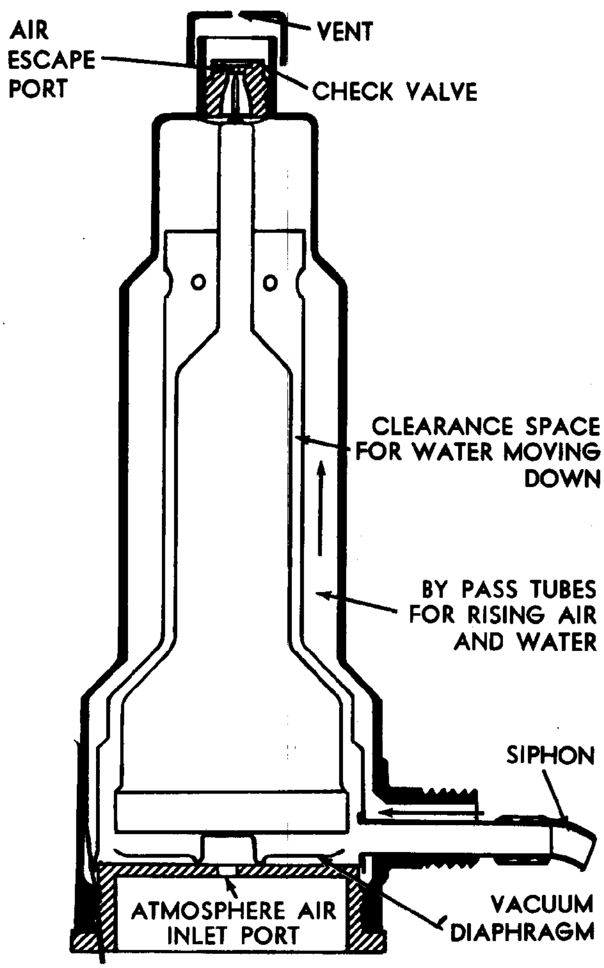


Figure 3-7. Radiator air valve.

b. Types. For a thorough coverage of the types of steam valves, see TM 5-652.

3-7. Condensate Pumps

a. Function. Condensate pumps are used where it is necessary to lift steam condensate in order to permit it to flow back into the boiler. This occurs where radiators or other steam-consuming apparatus are located below the boiler water line or so close to it that condensate cannot flow back to the boiler by gravity.

b. Types. A condensate pump assembly includes a receiver which receives condensate by gravity, a motor-operated pump, and a float-operated switch which operates the pump as required to remove water from the receiver. For further information see TM 5-652.

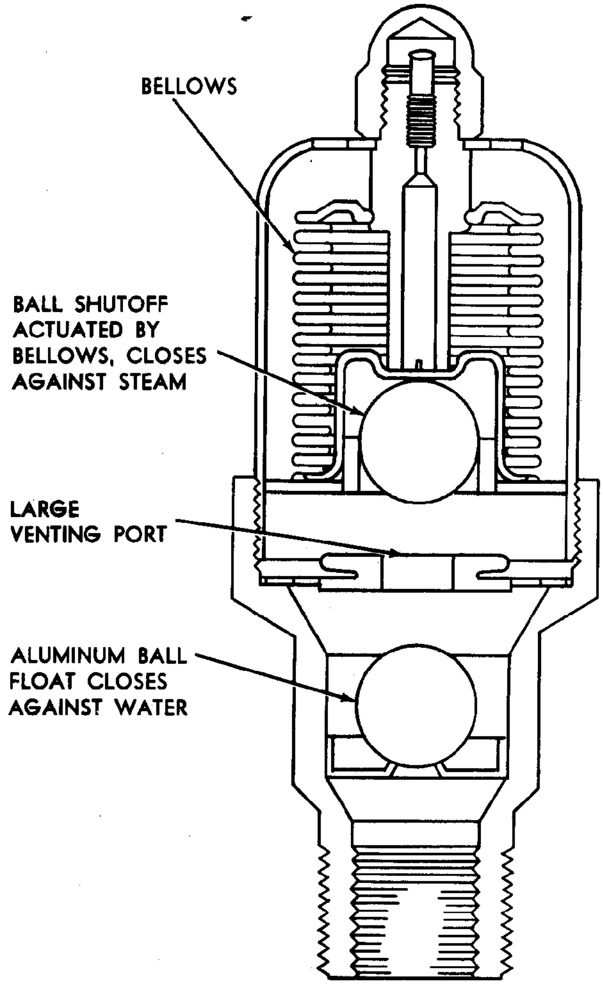


Figure 3-8. Air vent valve for mains.

3-8. Strainers

a. Function. Strainers are used in steam and water lines to prevent foreign matter from clogging small passages in equipment.

b. Types. Strainers may be installed in pipe lines or may be provided as a part of the equipment which they are intended to protect. Strainers are removable for cleaning and may be provided with a valve to permit blowing out of foreign material. For further information see TM 5-652.

3-9. Piping

Steel piping is used almost universally for steam heating systems. Fittings are threaded

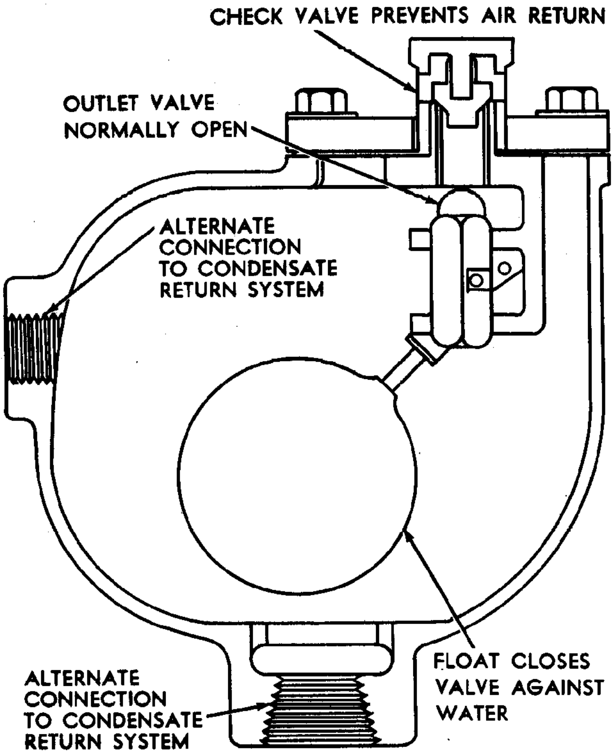


Figure 3-9. Air eliminator for two-pipe steam system.

cast iron or welded. The liberal use of unions is recommended in the connection of equipment such as traps, radiators, pumps, and automatic valves to permit their ready removal for repair or replacement. For detailed information on methods of assembling steel pipes, see TM 5-746.

3-10. Tools

Pipefitting equipment sets Nos. 1 and 2 are required for the assembly of steel piping. For information on their use, see TM 5-461.

Section II. DESIGN OF HEATING SYSTEMS

3-11. Sizing of Equipment

a. Radiators. The unit of radiator output, a square foot of radiation, is equivalent to 240 B.t.u. per hour for low-pressure steam systems (para 3-3*b*). The total amount of low-pressure steam radiation required in square feet to heat a given space is determined by dividing the total heat loss of that space, calculated as shown in paragraphs 2-1 through 2-6, by 240. For other steam pressures and temperatures, multiply the quantities thus obtained by the correction factors given in table H-6.

b. Convectors. Required convector capacities for low-pressure steam systems are determined in the same manner as radiator capacities.

3-12. Classification of Systems

Steam systems may be classified by any of the following methods:

a. Pressure. Steam heating systems are clasified as high-pressure, low-pressure, vapor, or vacuum systems depending upon the pressure conditions under which the system is designed to operate. A high-pressure system is designed to operate at pressures above 15 psig; a low-pressure system is designed to operate from 0 to 15 psig; a vapor system operates under both low-pressure and vacuum conditions without the use of a vacuum pump; and a vacuum system operates under low-pressure and vacuum conditions with the use of a vacuum pump.

b. Piping Arrangement. Steam heating systems using a single main and riser to convey steam to radiators or other heating units and to return condensate from them are known as one-pipe systems. Systems employing one set of mains and risers to distribute steam to the radiator or heating unit and a separate set of mains and risers to return condensate to the boiler are known as two-pipe systems. Steam systems may also be described as upflow or downflow, depending upon the direction of steam flow in the risers; and as dry return or wet return depending upon whether the condensate return mains are above or below the water line.

c. Method of Condensate Return. A system in which all of the condensate is returned to the boiler by gravity is known as a gravity-return system. When it is not possible for condensate to be returned to the boiler by gravity, either traps or pumps must be employed, and the system is known as a mechanical-return system. Systems in which the pressure condition varies between that of a gravity-return and a forced-return system can use alternating-return traps, and are known as alternating-return systems. When condensate is returned to the boiler by a pump at pressures above atmospheric, the system is known as a condensate-pump-return system. When condensate is pumped to the boiler under vacuum conditions, the system is known as a vacuum-pump-return system.

3-13. Piping Layout Principles

a. Steam and Condensate Flow. In the simplest of steam heating systems, steam generated by a boiler is led through a single pipe to a single radiator provided with a vent valve to remove air. If the connecting pipe were properly sloped, the condensate could return back through the same pipe to the boiler. In such a system steam and returning condensate would be running in opposite directions in the same pipe through its length. As water in changing to steam increases its volume over 1,600 times, the velocity of the steam in this pipe would be over 1,600 times the velocity of the returning water. Unless the pipe were of adequate size, the racing steam would pick up slugs of water and drive them against the next turn or restriction in the pipe causing a repeated banging sound known as water hammer (fig. 3-10). Whether or not water hammer takes place depends upon pipe size, whether the pipe runs horizontally or vertically, the pitch of the pipe if it runs horizontally, the quantity of condensate flowing against the steam, and the velocity of the steam. The simple system described is seldom if ever used, and variations in the design of steam systems are largely the results of improvements on this system made in an effort to eliminate water hammer without using abnormally large pipe sizes.

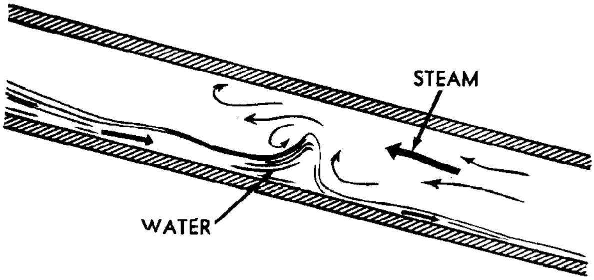


Figure 3-10. How water hammer develops.

b. Waterline and Pressure Drop. The flow of steam and condensate in steam systems is opposed by friction in the piping, fittings, valves, and other restrictions. This resistance is overcome by the difference between the pressure developed in the boiler and the reduced pressure caused by the condensation of the steam at the point of use. The boiler and wet return form a U (fig. 3-11) with the boiler steam pressure on top of the water at one end and the steam main pressure on top of the water at the other end. The difference between these two pressures is the pressure drop in the system, and the water in the far end of the system rises sufficiently to balance this pressure drop.

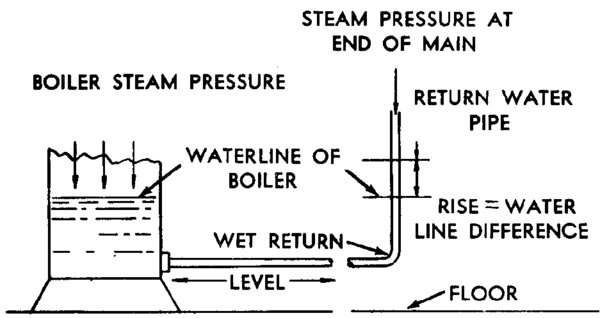


Figure 3-11. Effect of pressure drop in piping on waterline.

c. Air Venting. Even, fast heating of a steam system requires rapid venting of any air that may be in the system when heat is applied at the boiler. Radiator vent valves or traps are not sufficient to do this. Additional vents of large size must be provided to remove air from piping. As air is heavier than low-pressure steam, do not locate vent valves at the highest point of the system. If a steam main slopes downward away from the boiler and is connected to a return main at the end as is commonly done, the best location for the air vent for the main is on the top of the main just above the final drop below the boiler water line.

3-14. One-Pipe Systems

a. Description. This type of system is best adapted to small installations where low cost and ease of operation are important. It is not suited to close automatic control. If used in large installations it will not necessarily result in low first cost because of the necessity of using larger pipes than are required for two-pipe systems to eliminate water hammer. Each radiator or other heating unit in a one-pipe system is equipped with a thermostatic air valve and, in addition, larger air valves are installed at the end of steam mains. It is highly desirable that these valves be of the vacuum type which contain a small check valve to prevent the air from flowing back into the system when heat input is reduced. Such valves maintain vacuum conditions in the system and permit continued steam generation at subatmospheric pressures and consequently lower steam temperatures. They thus maintain heat output over a longer period and give more uniform temperature conditions in the spaces to be heated. Heating units may be provided with shutoff valves on the connection to the unit (fig. 3-12), but these valves cannot be partly closed to throttle heat input because the restricted opening will create water hammer and probably prevent water from draining from the radiator. Where it is desired to throttle steam input at the radiator or where the quantity of condensate formed is great, as in some unit heater installations, two radiator connections can be provided as shown in figure 3-13.

(1) *One-pipe upfeed gravity system.* In this system the supply main rises to its highest point directly above the boiler (fig. 3-14) and

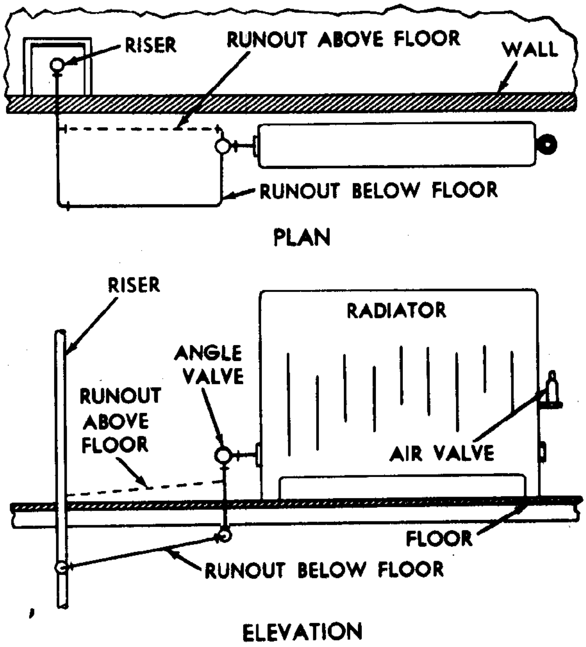


Figure 3-12. Radiator connections for one-pipe steam systems.

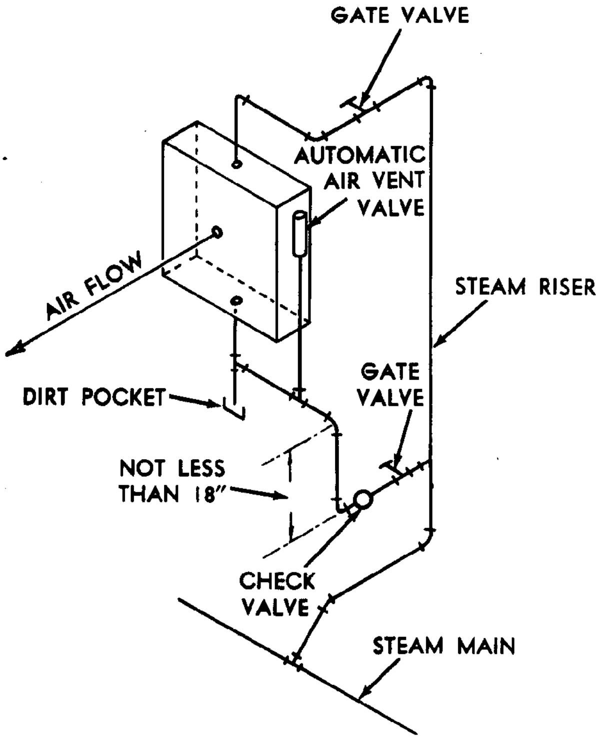


Figure 3-13. Unit heater connections for one-pipe steam systems.

then slopes downward away from the boiler carrying steam to the various risers. The main continues above the water line until it returns to the boiler where it drops below the water line and reenters the boiler. Thus, in all steam mains, which are the most critical portion of the system, steam and condensate are always flowing in the same direction. Steam and condensate flow in opposite directions in the risers only. In the system shown in figure 3-15 a wet return has been run directly under the supply main. In addition to draining the end of the supply main through the return, each riser has been continued downward to the return main. Thus the supply main is relieved of all condensate except that formed in the main proper. Such connections are desirable where the building is large and one main serves many radiators.

(2) *One-pipe downfeed gravity system.* This system, shown in figure 3-16, introduces an added improvement in that steam is delivered downward through the risers in the same direction as condensate flow. In this system the only line in which steam and condensate are flowing in opposite directions is the vertical riser directly off the boiler, and here the only condensate present is that formed by heat lost from the riser pipe.

b. Pipe Sizing. Tables of steam pipe capacities for low-pressure systems are given in appendix I. Capacities are expressed in square feet of equivalent direction radiation (EDR) for various allowable pressure drops per 100 feet of equivalent pipe length. The method of sizing outlined below is usually limited to systems in which the total length of the longest circuit is not greater than 100 feet. For larger systems it is suggested that the total drop be not over one-fourth psi and the method given here be followed with the exception that column C should be used where column D is indicated, and columns R and Q used in place of columns U and T. Pipe sizes can be determined as follows:

(1) For the steam mains and dripped

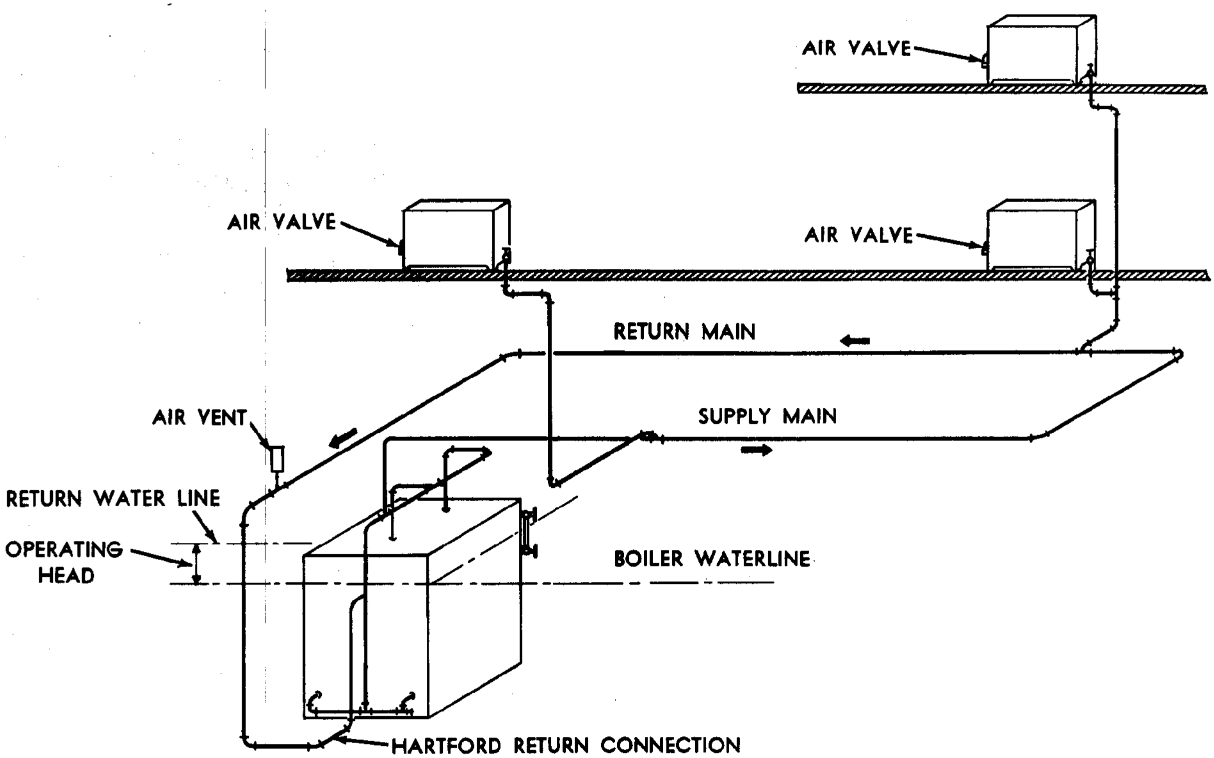


Figure 3-14. One-pipe upfeed air-vent system with dry return.

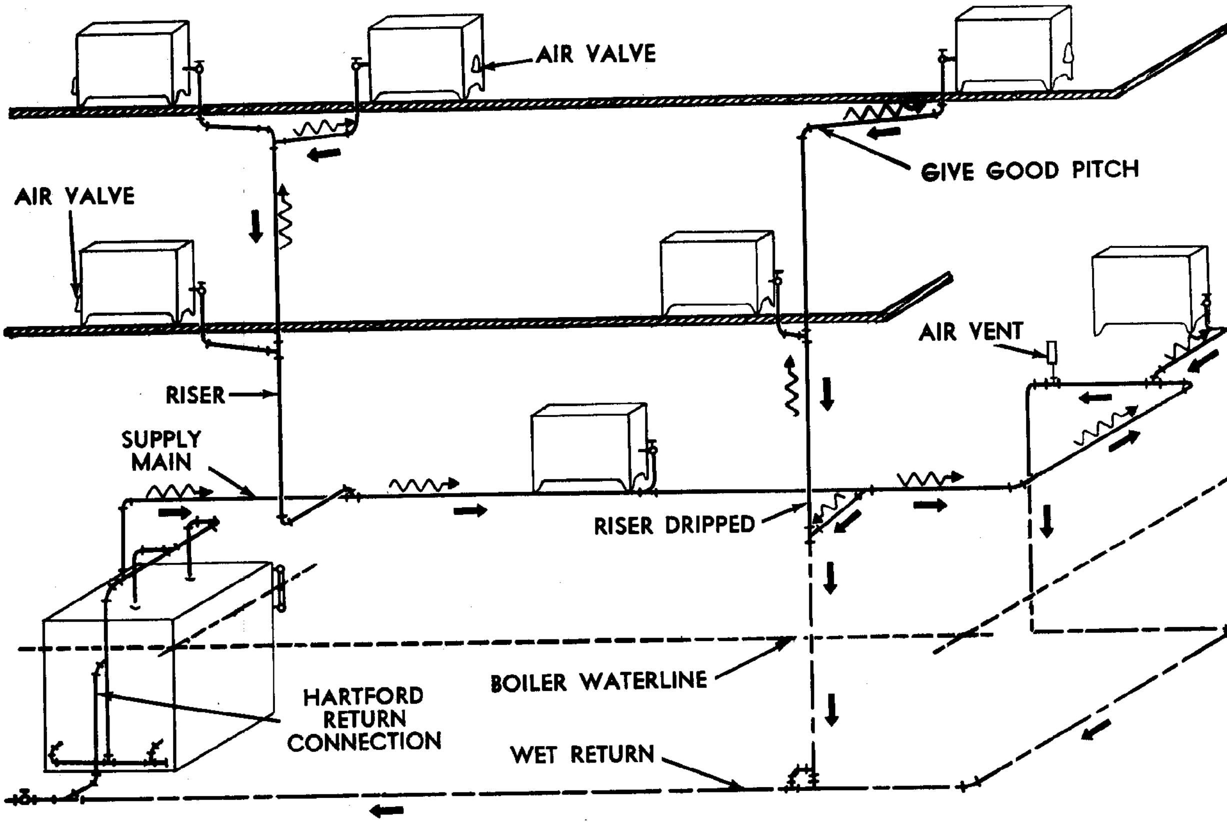


Figure 3-15. One-pipe upfeed air-vent system with risers dripped to wet return.

run-outs to risers where the steam and condensate flow in the same direction, use column D.

(2) Where the riser run-outs are not dripped and the steam and condensate flow in opposite directions and also in radiator run-outs, use column L.

(3) For upfeed steam risers carrying condensate back from the radiators, use column J.

(4) For downfeed systems in selecting riser sizes, use column H.

(5) For radiator valves and radiator connections, use column K.

(6) For dry return mains, use column U.

(7) For wet return mains, use column T.

c. Design Detail. In the installation of steam systems, it is absolutely necessary that all pipes be properly pitched to allow the drainage of condensate. See that the pitch of mains is not less than ¼-inch in 10 feet. Have the pitch of horizontal run-outs to risers and radiators not less than ½ inch per foot. Where this pitch cannot be obtained, have run-outs over 8 feet in length one size larger than called for in the riser table (figs. 3-17 & 3-18). It is not desirable to have a main of less than 2-inch diameter. Have the diameter of the far end of the supply main not less than one-half the diameter at the largest part. Where supply mains are decreased in size, they are dripped or provided with eccentric couplings flush on the bottom (fig. 3-19). Where it is necessary to loop mains around obstructions, provided an equalizing line and cleanout tee. In the installation of steam systems, pay particular attention to allowances for expansion of steam pipes. Have every long pipe free at one end and so arranged that connections or branches are not made immovable by structural members of the building. Support steam mains with hangers, but branches to the risers must be allowed to move to take care of expansion. Each

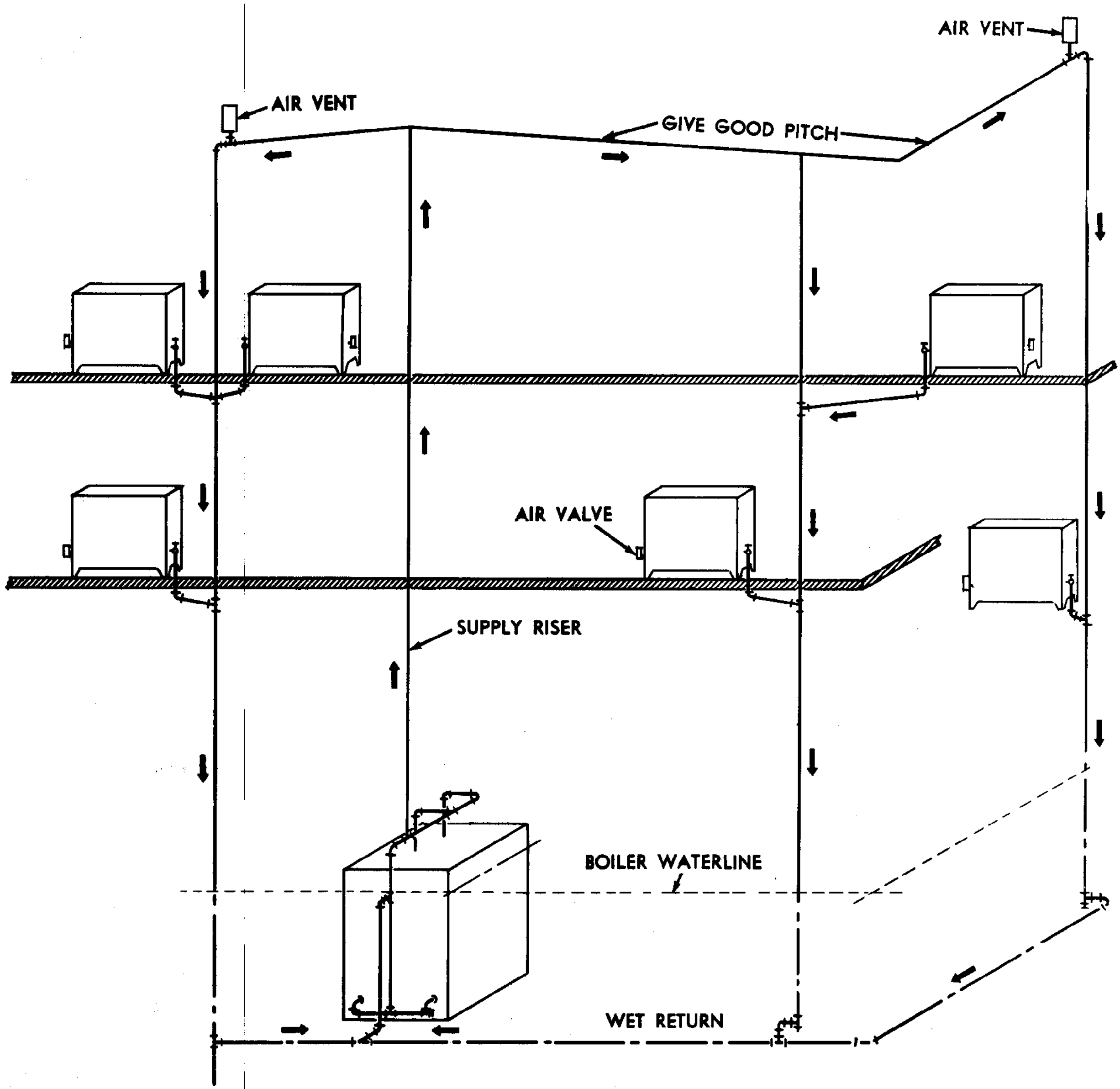


Figure 3-16. One-pipe drumfeed air-vent system.

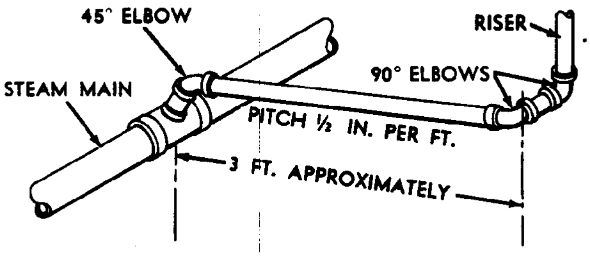


Figure 3-17. Steam run-outs where risers are not dripped.

vertical pipe should be connected at the bottom with an elbow to a horizontal nipple or piece of pipe which is in turn connected through a second elbow, lying on its side, to the branch or run-out from the steam main (fig. 3-17). Sectional heating boilers usually have several outlets in the top. Use two or more outlets wherever possible to reduce steam velocity and prevent the carryover of water through the vertical uptake into the steam main. Make the

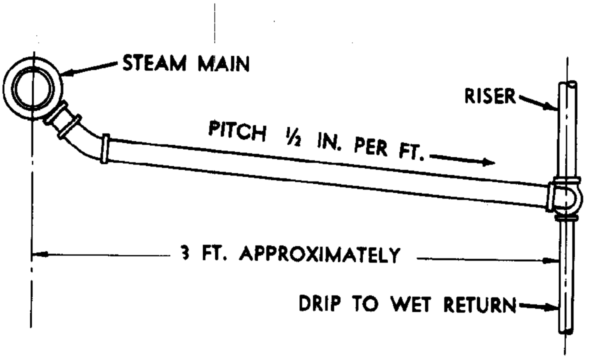


Figure 3-18. Steam run-outs where risers are dripped.

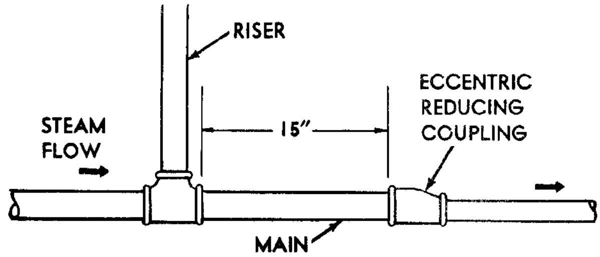


Figure 3-19. Method of changing size of steam main when run-outs are taken from top.

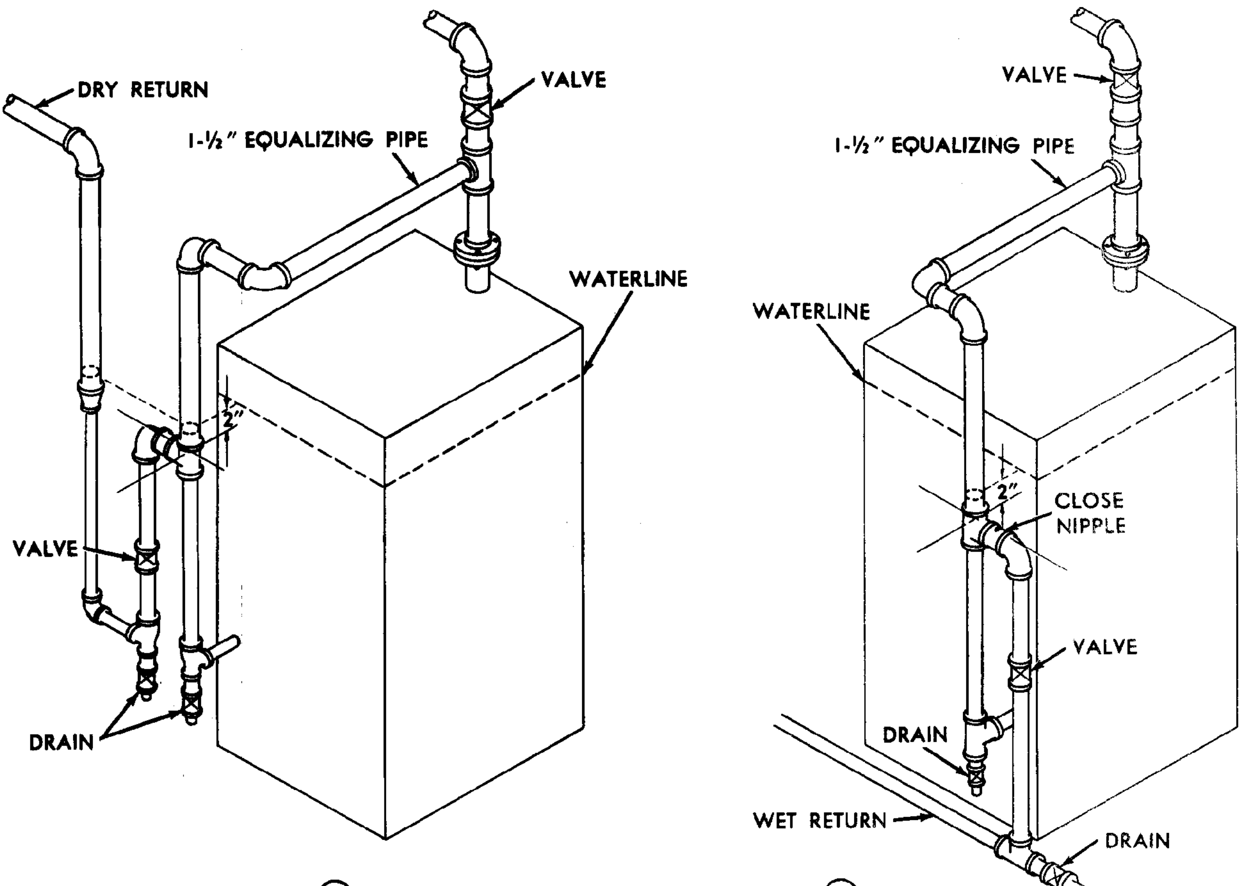


Figure 3-20. Hartford return connection.

return connection to the boiler with a Hartford loop (fig. 3-20). This connection will prevent the boiler from losing water under any circumstances short of a leak in the boiler itself. Piping connections for two or more boilers in parallel are shown in figure 3-21. Where it is necessary to elevate a steam main to a higher level, provide a drip connection (fig. 3-22) to relieve the main of condensate. Steam mains are looped around obstructions by providing a small pipe below the obstruction to carry off the condensate as shown in figure 3-23. Dry re-

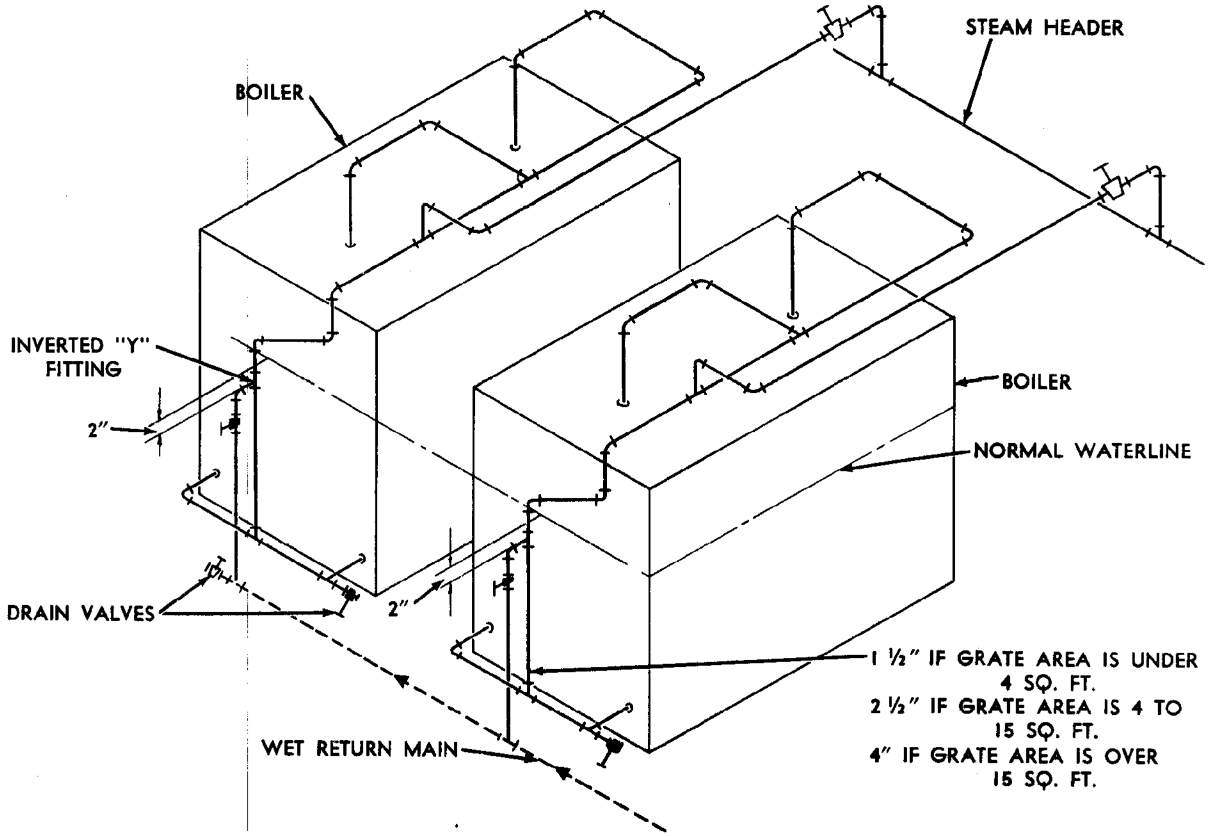


Figure 3-21. Connections for boilers in parallel.

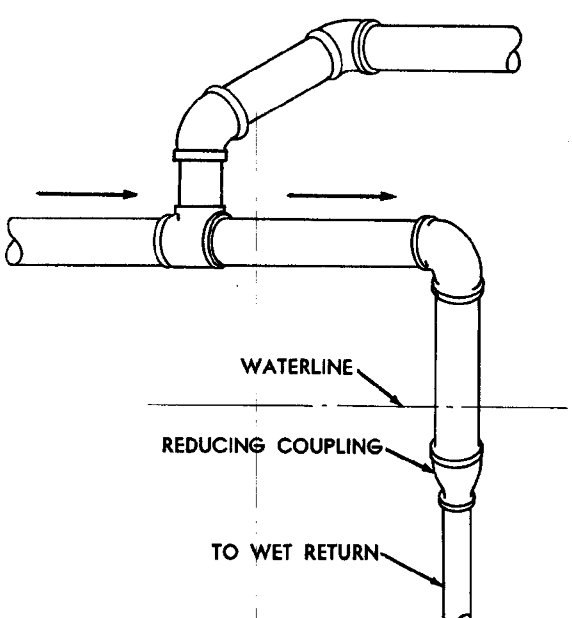


Figure 3-22. Dripping main at base of risers.

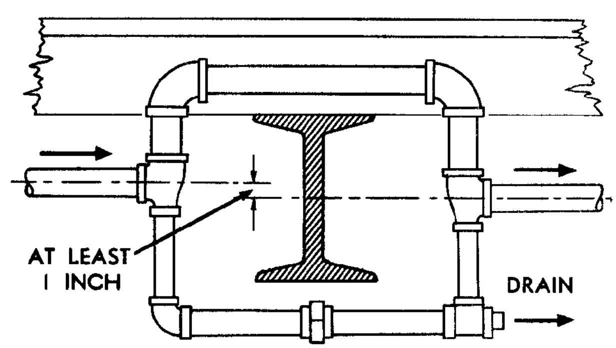


Figure 3-23. Looping steam main around obstructions.

turn mains are similarly looped by providing a small line above the obstruction to carry the air (fig. 3-24).

3-15. Two-Pipe Systems

a. Description. Two-pipe systems may operate under high pressure, low pressure, vapor or vacuum conditions, and either upflow or

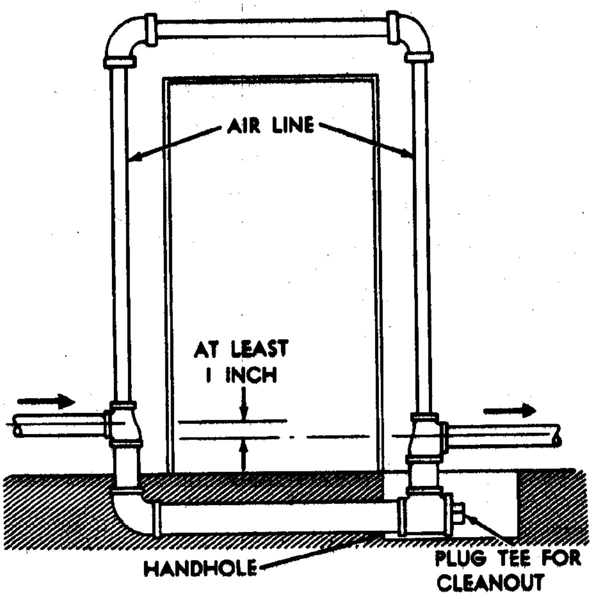


Figure 3-24. Looping dry return main around obstruction.

downflow steam distribution can be used. They have the advantages of permitting modulation or adjustment of steam flow to individual heating units or portions of the system and of using smaller pipes than one-pipe systems.

(1) *Two-pipe high-pressure system.* A two-pipe high-pressure system is shown in figure 3-25. A feature of this system is that because of the high pressure, usually from 30 to 150 psig, and the great difference in pressure between steam and return mains, it is possible to locate the returns above the heating unit and force the condensate upward to the return main.

(2) Two-pipe low-pressure system. The two-pipe low-pressure system shown in figure 3-26 uses air valves which permit air to re-enter the system when the radiators cool. These systems cannot operate under a vacuum. They are seldom used because of the superior advantages of two-pipe vapor systems. When the boiler pressure falls and air re-enters the sys-

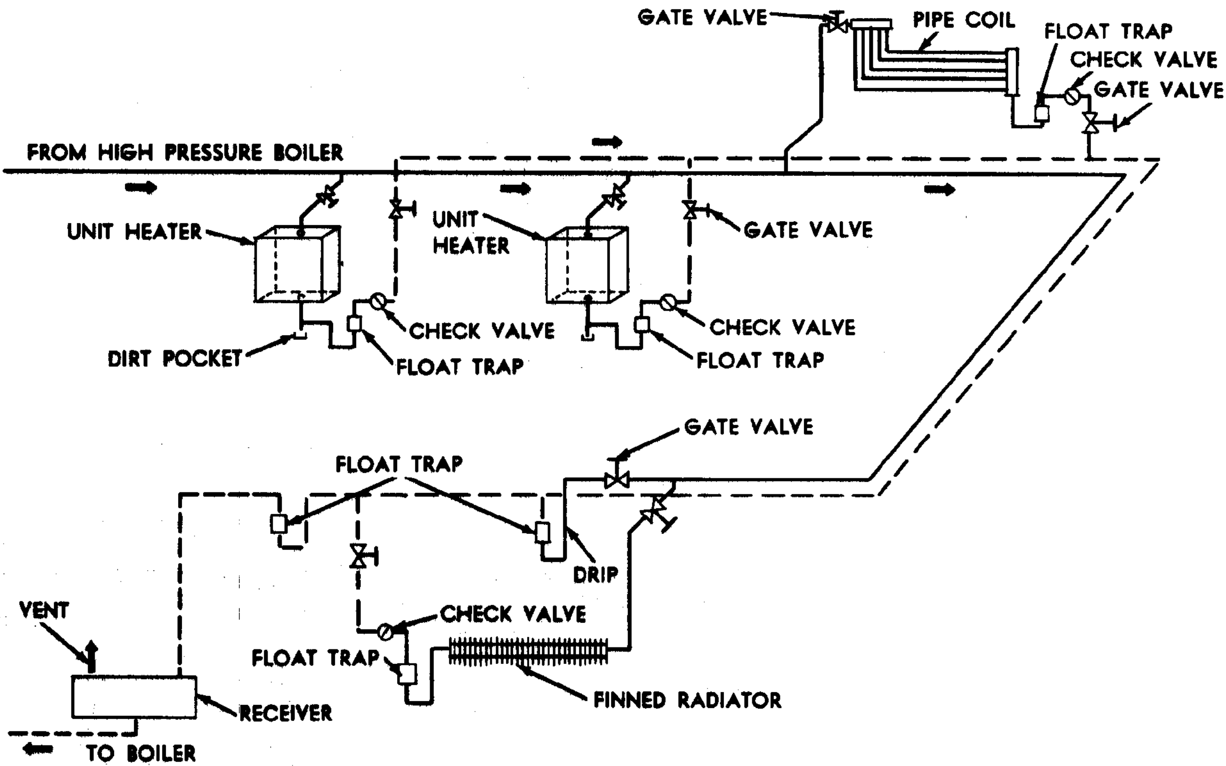


Figure 3-25. Two-pipe high-pressure system.

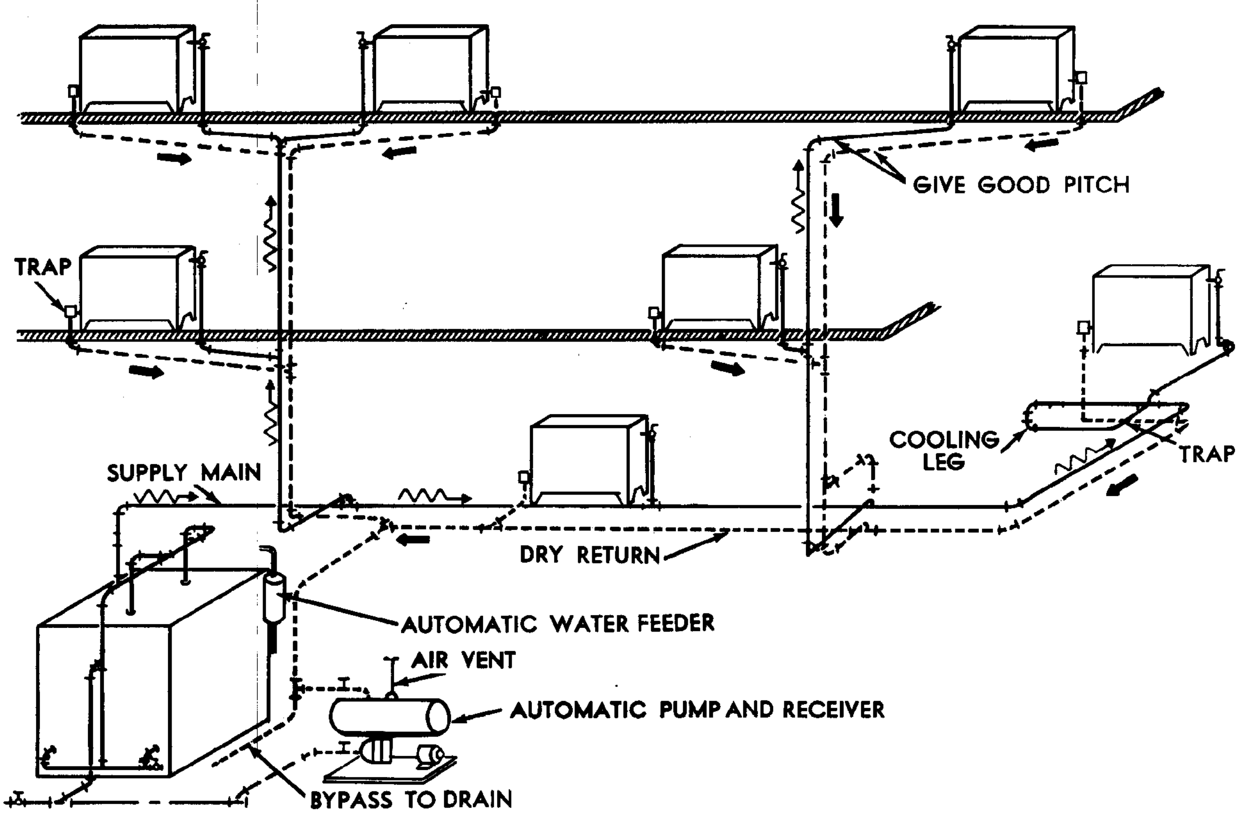


Figure 3-26. Two-pipe low-pressure system.

tem, the radiators cool rapidly and do not heat again until boiler heat input is increased and steam pressure rises. These systems have the additional disadvantage of corroding to a greater extent due to the repeated admission of air. Low-pressure systems do have the advantage, however, of returning condensate to the boiler readily. Therefore, the condensate pump shown in figure 3-26 is not necessarily a part of a two-pipe low-pressure system.

(3) *Two-pipe vapor system.* Two-pipe vapor systems operate over a range of pressures varying from several pounds gage down to 20 inches of vacuum, depending upon the tightness of the system and the air eliminating valves used. An upfeed system using automatic return traps is shown in figure 3-27, and a downfeed vapor system is shown in figure 3-28. Essential elements of these systems are the vacuum type air valves which close to prevent the reintroduction of air into the system when the pressure drops below atmospheric. This makes it possible for the system to operate under vacuum conditions and continue to give off heat at lower steam temperatures for a period of from 4 to 8 hours. Because steam pressure is trapped off at radiator outlets and air cannot reenter the return through the air valves, there is a tendency for condensate to build up and be retained in the return system. To overcome this, many systems employ an automatic return trap or alternating receiver. Connections for the installation of this trap are shown in figure 3-29. In operation, when the receiver empties, the float falls, and the balance line of the steam main is closed off. As boiler pressure is also closed off from the return line by a check valve at the base of the boiler, condensate is permitted to flow into the receiver, and any air that comes with it escapes through the air valve. As the receiver fills, the float rises to a point where it simultaneously closes off the air-vent line and opens up the balance line from the steam main.

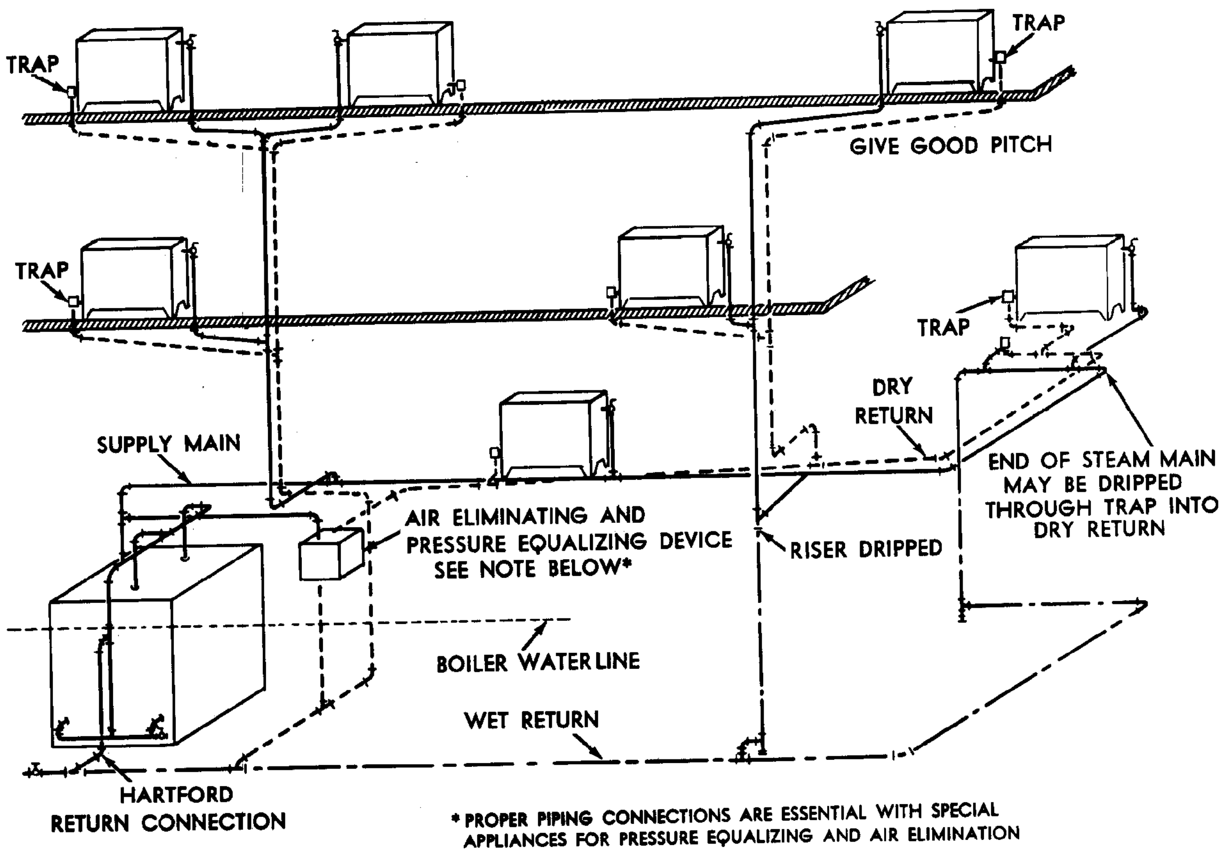


Figure 3-27. Two-pipe upfeed vapor system.

This forces the accumulated water into the boiler. A check valve prevents this water from reentering the return system.

(4) *Two-pipe vacuum system.* Upfeed and downfeed two-pipe vacuum systems are shown in figures 3-30 and 3-31. A vacuum steam heating system differs from a vapor system only in that the differential pressure between the supply piping and the return piping is insured in part by operation of a pump which draws both condensate and the air from the return system. The pump prevents water from building up in the return main and can, if necessary, lift condensate by suction from points below the pump. This makes it possible to install radiators close to or even below the boiler water line, a practice not possible with a vapor system. For these reasons and because the use of a pump insures a vacuum throughout the entire return system, vacuum steam heating systems are frequently used in very large buildings. Return lines are so sloped that condensate drains to the vacuum pump. Where it is necessary to return condensate from a point below the pump, a return lift connection as shown in figure 3-32 is used. These fittings, by arranging the alternate formation of slugs of air and water, permit the pump to raise water by a percolating action.

b. Pipe Sizing. The tables in appendix I can be used to size piping for two-pipe steam, vapor and vacuum systems. As these systems are frequently large it is best to first establish an allowable total pressure drop per 100 feet. The allowable pressure drop should not exceed one-half the maximum operating boiler pressure. After establishing the allowable pressure drop, determine the total equivalent length of run. This should be the actual length of the longest circuit, supply and return, doubled to allow for the resistance of fittings.

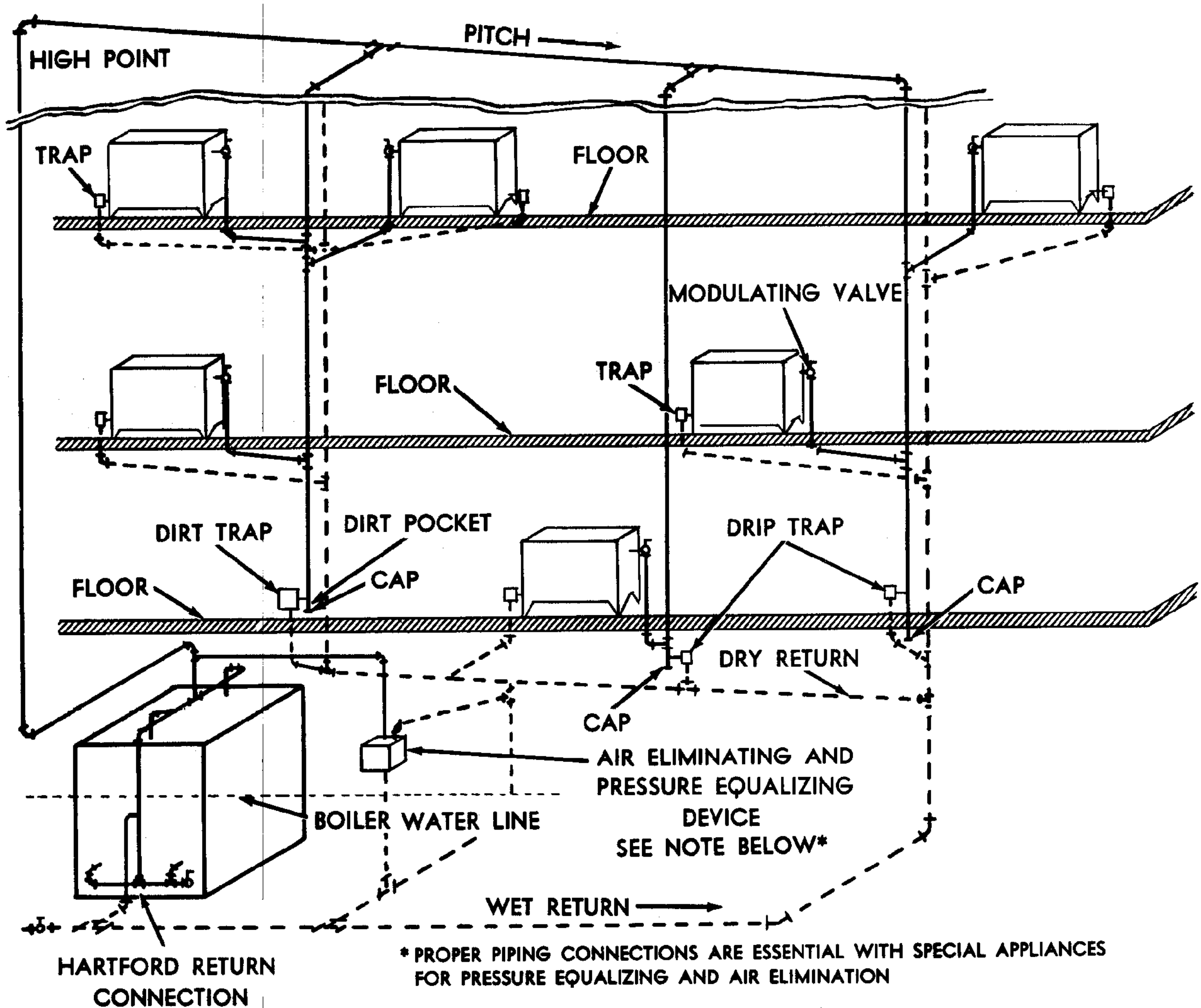


Figure 3-28. Two-pipe downfeed vapor system.

Example:

Given: Maximum boiler pressure, 2 psi
Actual length of longest circuit, 200 feet

Then: Maximum design pressure drop $=2/2=1$ psi
Equivalent length of longest run $= 200 \times 2 = 400$ feet
Design pressure drop per 100 feet $= \frac{1 \times 100}{400} = \frac{1}{4}$ psi

(1) *Two-pipe vapor systems.* The total pressure drop of two-pipe vapor systems is kept low to insure condensate return and uniform steam distribution. A total pressure drop of ⅛ to ¼ psi is recommended. For a system with a design pressure drop of ⅛ psi per 100 feet with main runouts dripped, risers are from column D. Runouts not dripped are from column I. Upfeed steam risers are from column H. Return risers and mains are from column X. On a downfeed system the main vertical riser is sized from column H, but the downfeed riser from column D.

(2) *Two-pipe low-pressure systems.* Piping for two-pipe low-pressure systems can be sized in the same manner as piping for vapor systems except that the total pressure drops should be from ½ psi to 1 psi.

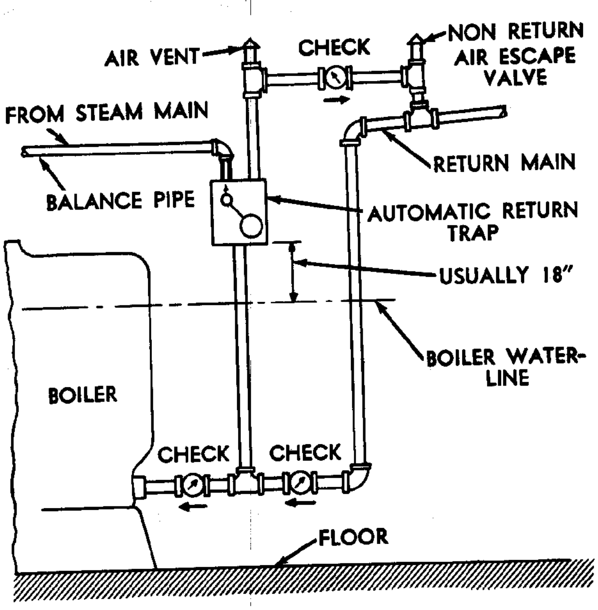


Figure 3-29. Connections for automatic return trap.

(3) *Two-pipe vacuum systems.* Two-pipe vacuum systems are usually designed with a total pressure drop varying from ¼ to ½ psi and sized in the same manner.

(4) *Two-pipe high-pressure systems.* Total allowable pressure drop in the supply portion of these systems can be large; 10 psi for a 30 psig system and 30 psi for a 150 psig system. As the return system is trapped off from the supply system and operates at low-pressure, the use of a design pressure for returns of ½ psi for 30 psig systems and 1 psi for 150 psig systems is recommended. Pipe sizes can then be selected from appendix I.

c. Design Details. The requirements for the pitchings of mains and horizontal runouts and the desirable minimum supply main size for two-pipe systems are the same as those given for one-pipe systems in paragraph 3-14c. Where it is necessary to lift condensate for a

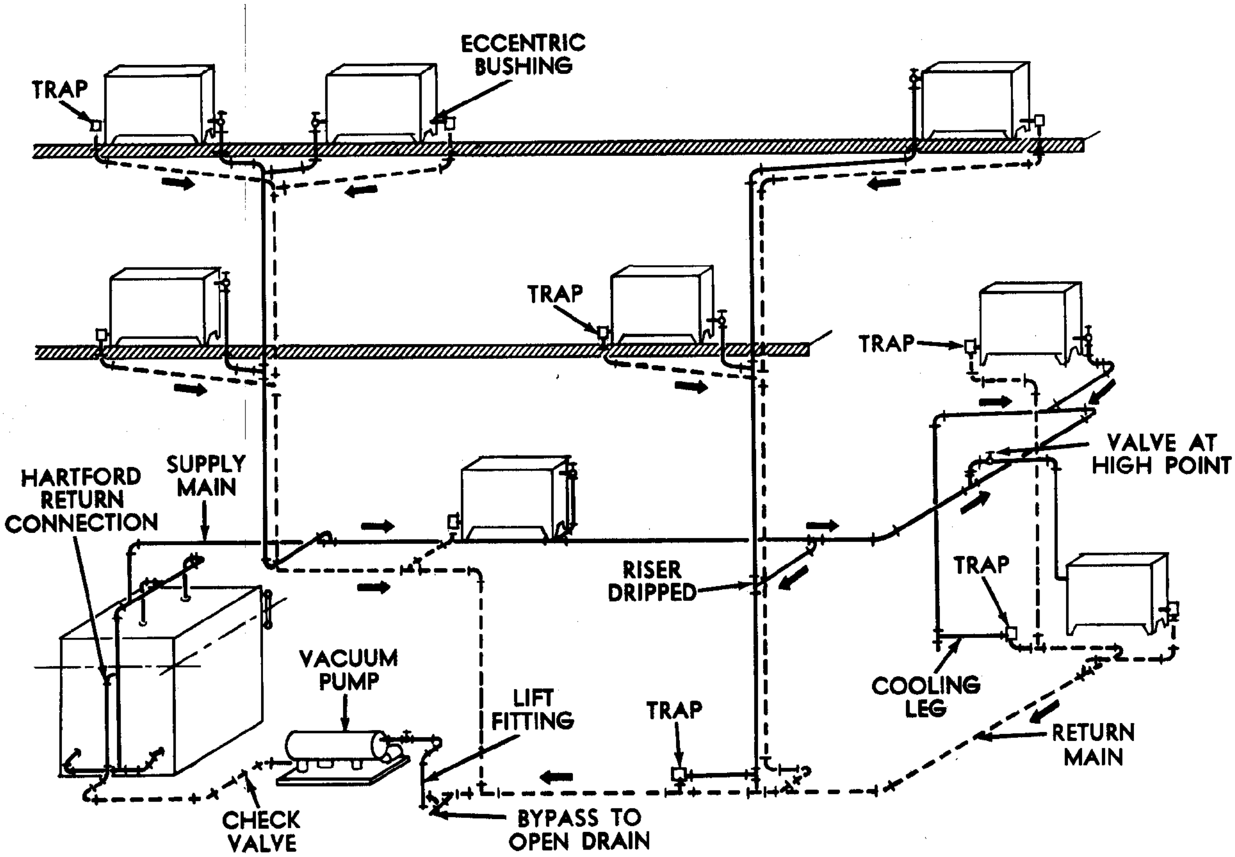


Figure 3-30. Two-pipe upfeed vacuum system.

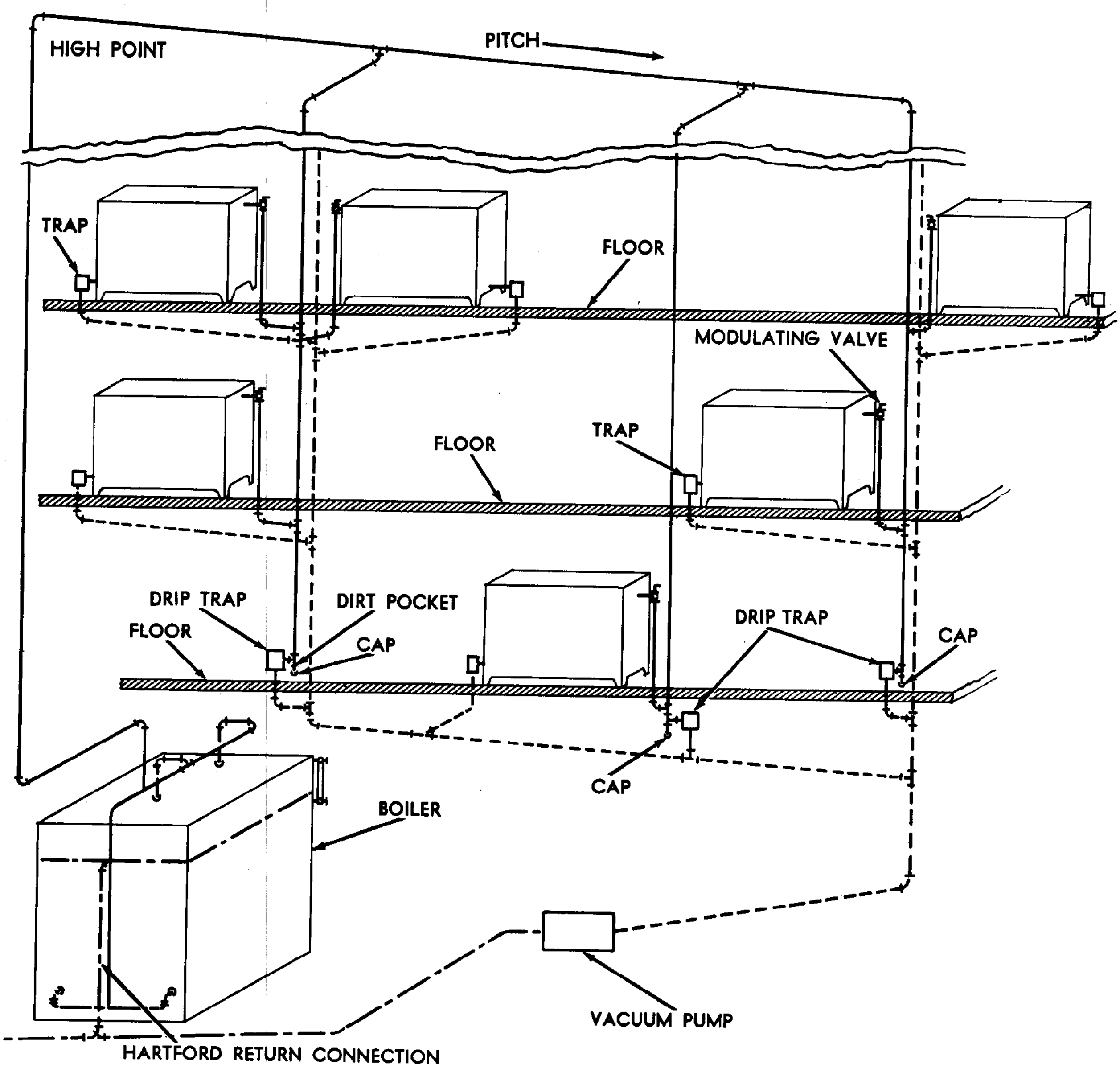


Figure 3-31. Two-pipe downfeed vacuum system.

distance greater than 5 feet in a vacuum system, several lift fittings can be used in series (fig. 3-33). These fittings are manufactured commercially in small and medium sizes, and larger condensate lifts can be made up out of stock pipe, as shown in the figure. In all cases it is desirable to provide means for draining the low point of lifts to eliminate the danger of freezing. In all two-pipe systems having dry-return lines, it is necessary to provide a trap between the steam-supply system and the condensate-return system at every point where they meet. A method of dripping a supply riser to the return main is shown in figure 3-34. Similarly when the ends of supply mains are vented to dry returns, a trap should be used as shown in figure 3-35. A combination float and thermostatic trap is recommended for dripping the ends of the steam main and risers into a dry return (figs. 3-36 and 3-37). These traps

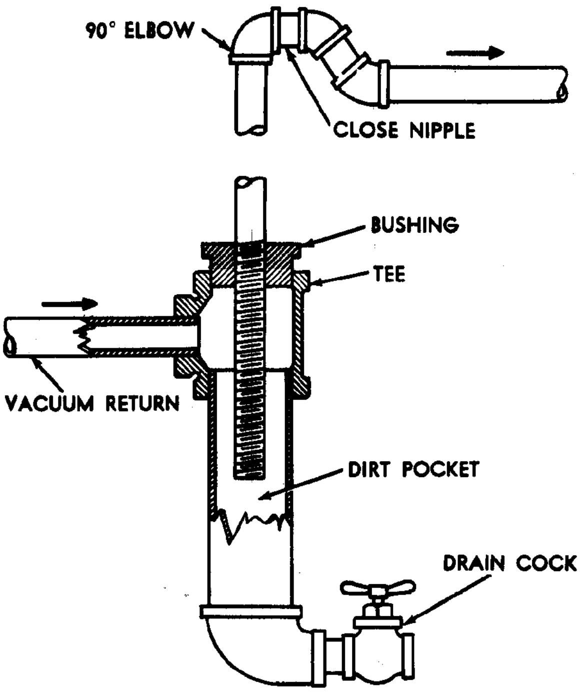


Figure 3-32. Detail of return lift at vacuum pump.

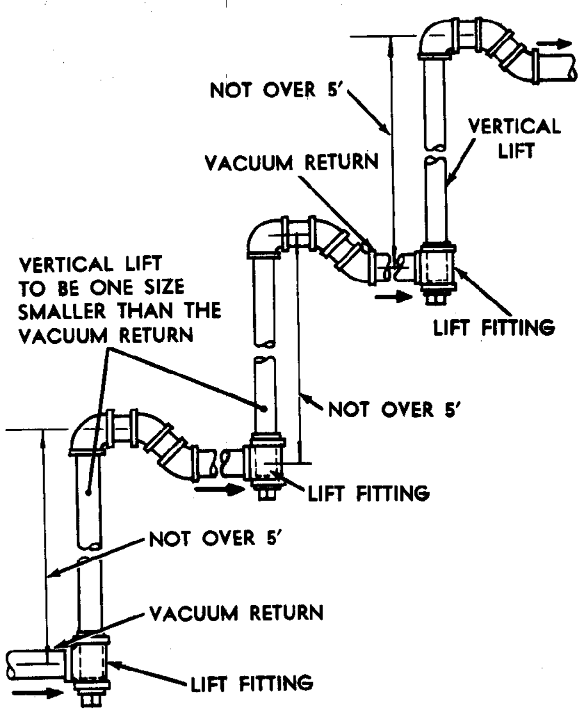


Figure 3-33. Method of making lifts of over 5 feet on vacuum systems.

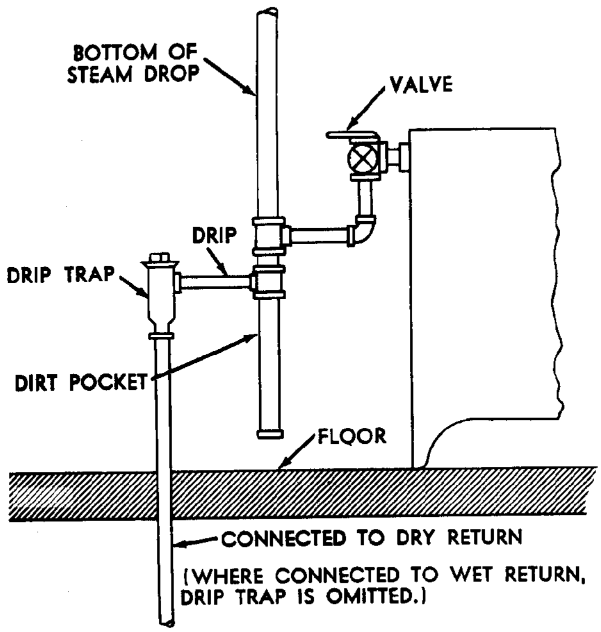


Figure 3-34. Drip connections at bottom of downfeed steam drop.

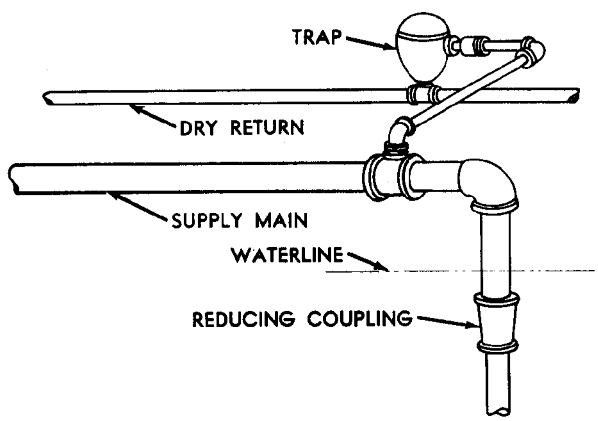


Figure 3-35. Venting of steam main into dry return.

will prevent condensate from backing up into the supply system under any condition. Traps should be protected wherever possible by dirt-pocket connections (fig. 3-38). Recommended methods of connecting radiators, convectors, and unit heaters in the two-pipe systems are shown in figures 3-39 through 3-43.

3-16. Radiator Location

For best heat distribution within the space served, radiators are located close to the great-

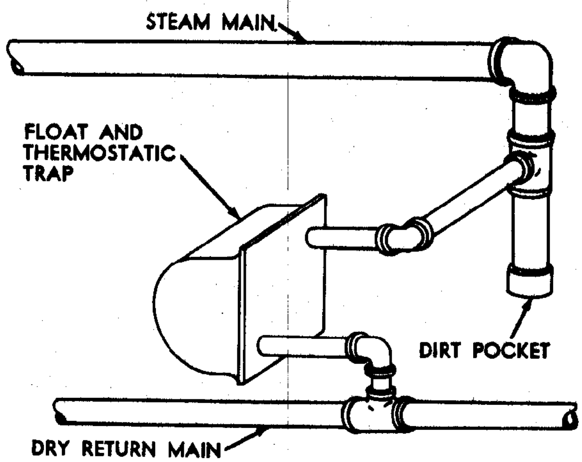


Figure 3-36. Dripping end of steam main into dry return.

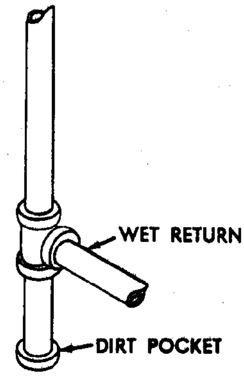


Figure 3-38. Dirt pocket connection.

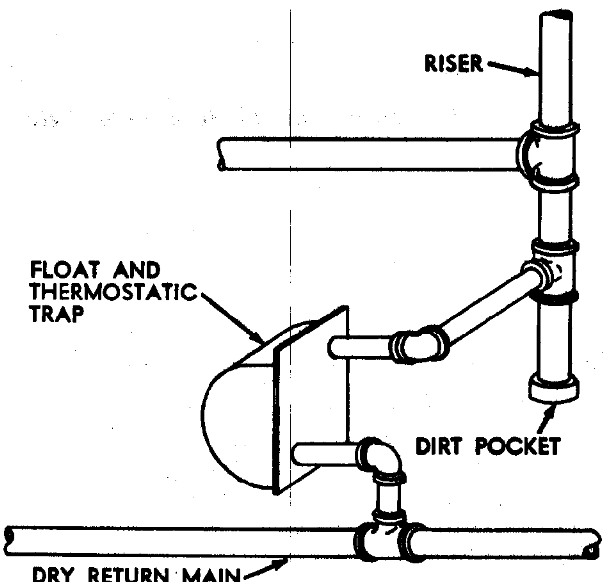


Figure 3-37. Dripping base of riser into dry return.

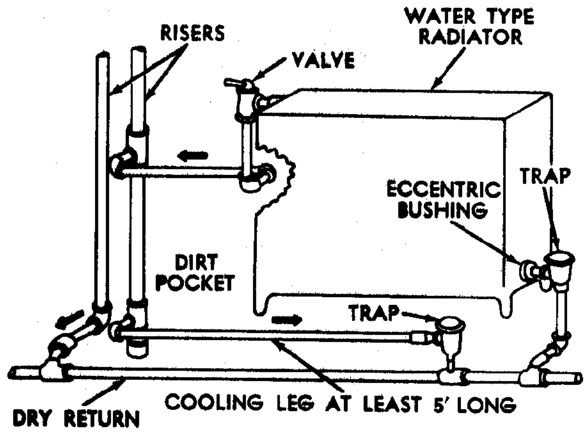


Figure 3-39. Two-pipe connections to standing radiator.

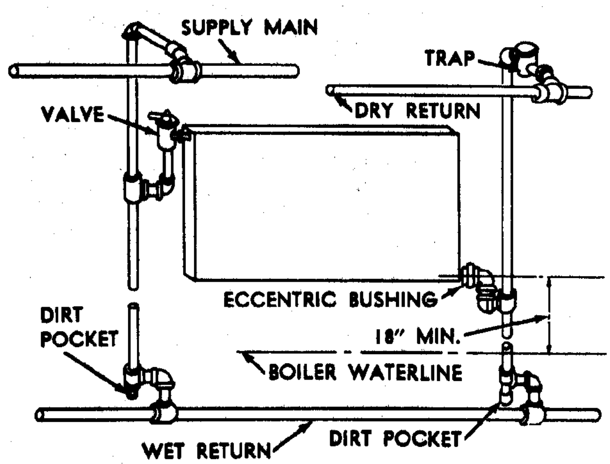


Figure 3-40. Two-pipe connections to wall radiator.

est source of heat loss. This will, in almost all cases, be along an outside wall, preferably under a window, where warm air currents rising from the top of the radiator will counteract the cold air which tends to fall from the cold glass surfaces and out over the floor. In installing steam radiators, take care to set them at a pitch so that all condensate will drain away. This means sloping radiators toward the single connection in the case of one-pipe systems and toward the return connection in the case of two-pipe systems.

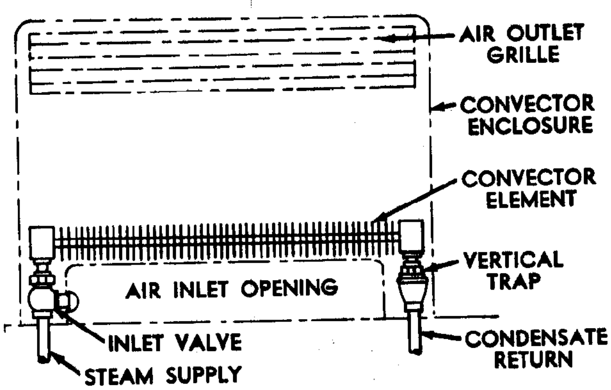


Figure 3-41. Two-pipe connections to convector.

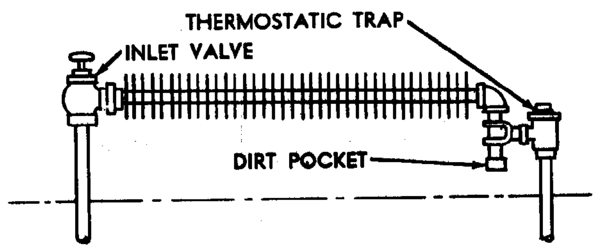


Figure 3-42. Two-pipe connections to finned tubing.

3-17. Insulation

The supply mains of steam heating systems are usually insulated to save unnecessary heat loss and to reduce the amount of condensate formed in the mains. Insulation for straight pipe is available in all common pipe sizes and is usually made either of 85 percent magnesia or of corrugated air-cell asbestos. This insulation splits in half and is applied by assembling it around the pipe and wrapping it with a cloth jacket which is usually supplied as part of the insulation (fig. 3-44). Fittings are covered with plastic insulating cement. Supply lines of low-pressure systems are usually covered with 1-inch thick insulating material where such lines run within buildings, and heat lost from the pipes is not entirely wasted. Where supply lines run outside and are exposed to subfreezing temperature, 2-inch thick insulation should be used. Return lines are seldom covered unless exposed to freezing temperature. On high-pressure systems which carry correspondingly higher temperatures, these thicknesses should be increased, particularly for large pipes over 2 inches in diameter.

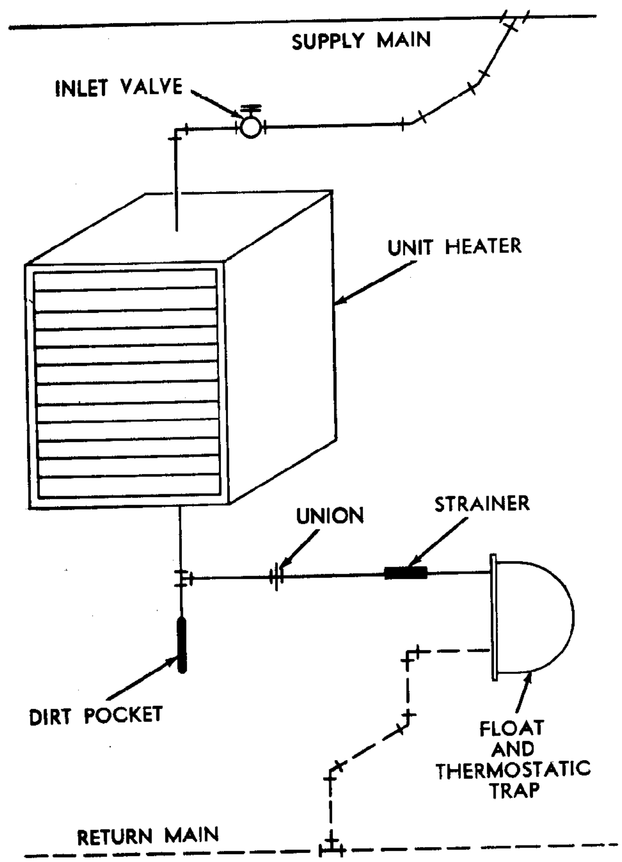


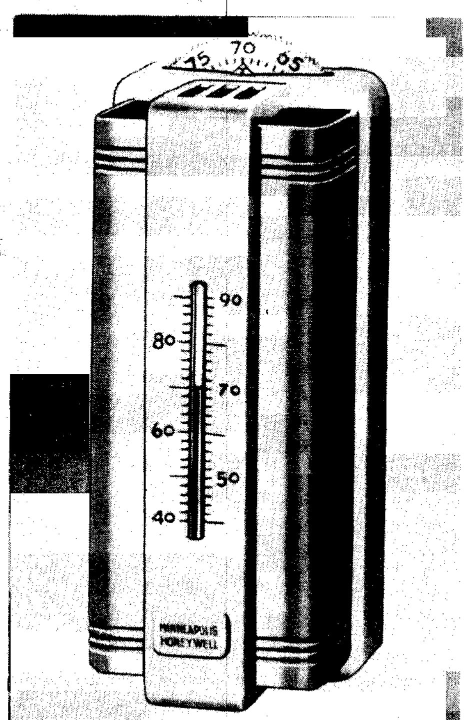
Figure 3-43. Two-pipe connections to unit heater.

Figure 3-44. Magnesia pipe insulation with canvas jacket.

Section III. CONTROL

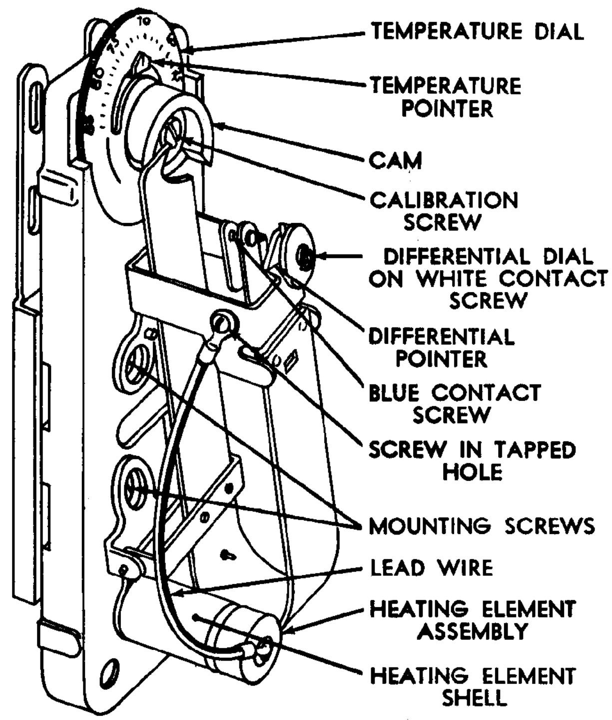
3-18. Purpose

Controls for steam heating systems are of two types; operating controls which actuate and regulate the operation of a system so that it meets the heating requirements of the space it serves, and safety controls which protect the system and the building in which they are installed from damage due to faulty operation. Operating controls allow heating when required and reduce or prevent heating when it is not required and thus save fuel. A tremendous amount of energy could be stored in a closed steam system if there were no limits on the steam pressure; however, if this energy were released suddenly, as would occur, if the boiler were to crack, the damage done to life and property would be considerable. For this reason adequate and, in some cases, duplicate safety controls are justified.



① COVER IN PLACE

Figure 3-45. Room thermostat.



② COVER REMOVED

Figure 3-45—Continued.

3-19. Operating Controls

a. Thermostats. Automatic heating equipment is best controlled by a thermostat located in the space to be heated. Comfortable temperatures and economical use of fuel are dependent upon the proper performance of the thermostat and the controls to which it is connected. They should be kept in good condition by an experienced repairman.

(1) *Description.* The thermostat is an adjustable temperature-sensitive device which, through change in dimensions of a bimetallic strip, or change in the space occupied by a confined vaporized liquid, or change in resistance in an electric circuit, reports temperature changes by means of electric or pneumatic circuits to other control devices. These in turn regulate the generation or distribution of steam. A typical room thermostat is shown in figure 3-45. This thermostat, like many others,

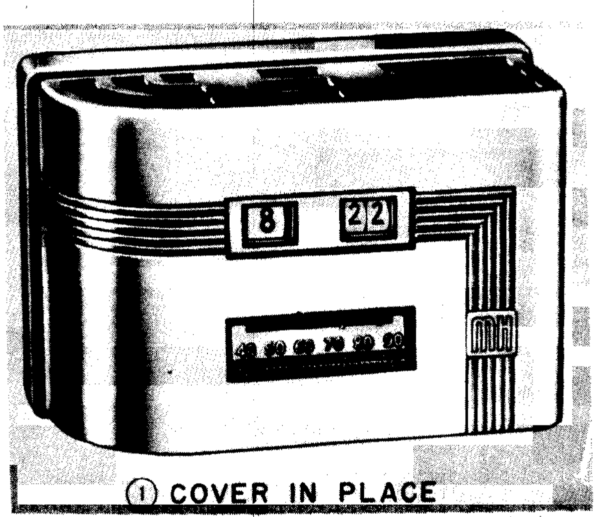


Figure 3-46. Room thermostat with clock control.

has an adjustable operating differential (room temperature change required to cause the thermostat to operate the control mechanism) as well as a built-in heating element. It is the purpose of the heating element to artificially apply heat to the thermostat during the period that steam is being distributed and thus anticipate the response of the heating system and prevent overshooting of room temperatures. As operating characteristics of various makes of thermostats differ, manufacturers' instructions should be strictly followed in installing and adjusting these instruments. The clock type thermostat shown in figure 3-46 has the added feature of automatically reducing the controlled temperature at night. Many independent tests have demonstrated that reducing night thermostat settings ten degrees will save as much as 10 percent in fuel cost.

(2) *Application.* When used with hand-fired coal boilers, thermostats normally control the operation of a two-position motor which in turn opens the draft damper and closes the check damper on a demand for heat. A manually operated switch can also be included at the boiler so that the draft may be controlled during firing operations. When used with automatic stokers, a call for heat by the thermostat results in full operation of the stoker fan and fuel feed. When the thermostat is satisfied, the

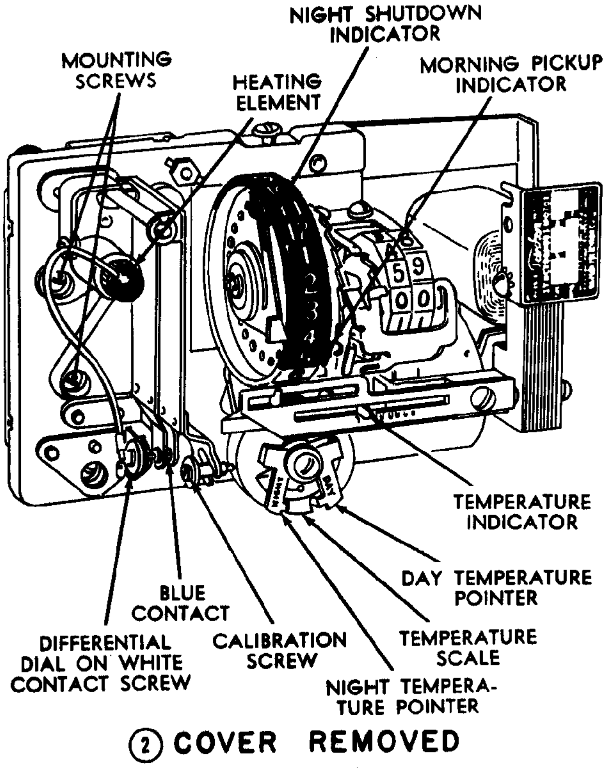


Figure 3-46—Continued.

fire is kept alive by a timing mechanism which operates the stoker for a few minutes at regular intervals whether heat is needed or not. When used with automatic oil burners or gas burners, room thermostats usually turn the burner either completely on or off as heat is required. In addition these burners are equipped with automatic ignition and safety devices to ensure that ignition takes place each time burner operation is called for. Steam systems serving large buildings may be "zoned" with a thermostat in each zone controlling an automatic steam valve in the main serving that zone in order to provide closer temperature control in various sections of the building. For such systems it is necessary to control boiler operation by other means such as a pressure-operated switch to maintain constant steam pressure, or a special thermostat located outdoors to vary the length of boiler operating time with outside temperature. Control of fuel input by other than room temperature is not recommended unless the system is zoned or it

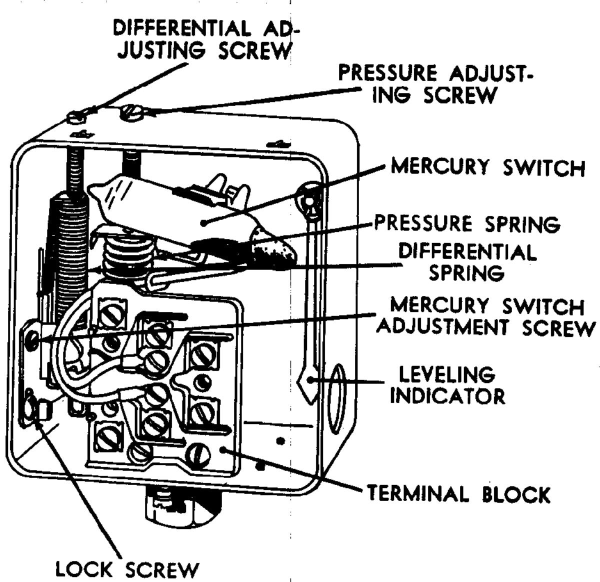


Figure 3-47. Pressure control, 0 to 10 pound per square inch range (cover removed).

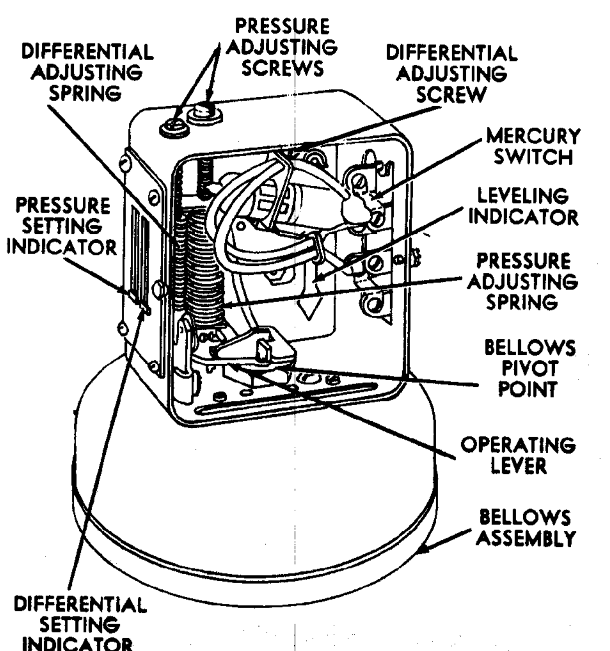


Figure 3-48. Pressure control, 0 to 16 ounce per square inch range (cover removed).

is impossible to find a satisfactory room thermostat location. The maintenance of steam pressure when heat is not required almost always results in added fuel consumption. Correct installation and connection of thermostats

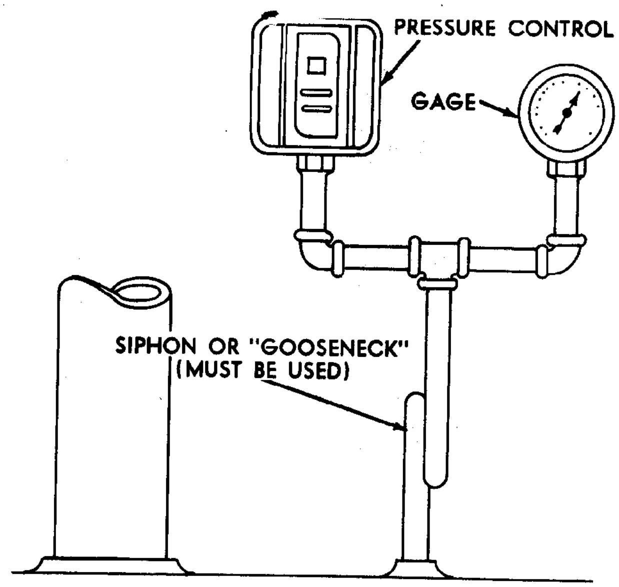


Figure 3-49. Pressure control and pressure gage mounted on boiler.

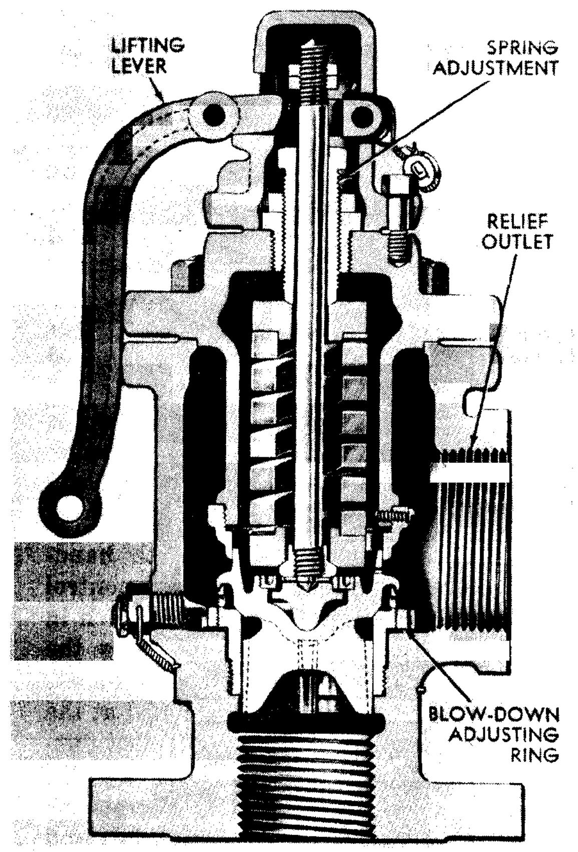


Figure 3-50. Cross section of pressure-relief valve.

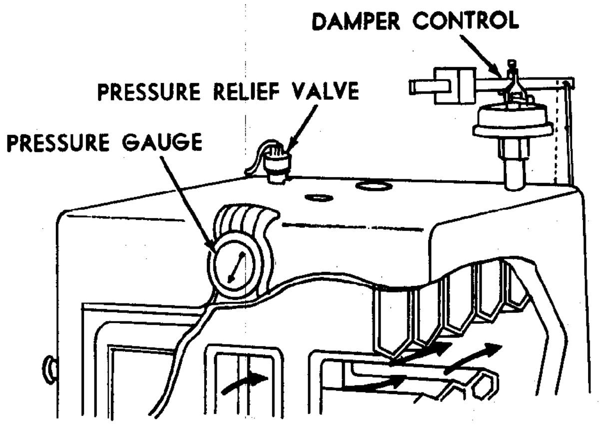


Figure 3-51. Location of pressure-relief valve on boiler.

and related controls should not be difficult as long as manufacturers' instructions are followed. Control terminals are either color coded, code lettered, or numbered, and manufacturers' wiring diagrams are usually simple and clear.

(3) *Location.* Room thermostats are located in a space which is representative of the majority of important spaces served by the heating system. They are mounted at eye level on an interior partition column where air can circulate freely around them. Do not mount them on outside walls or where subjected to cold drafts from outside doors or stairways. They should not be installed too close to radia-

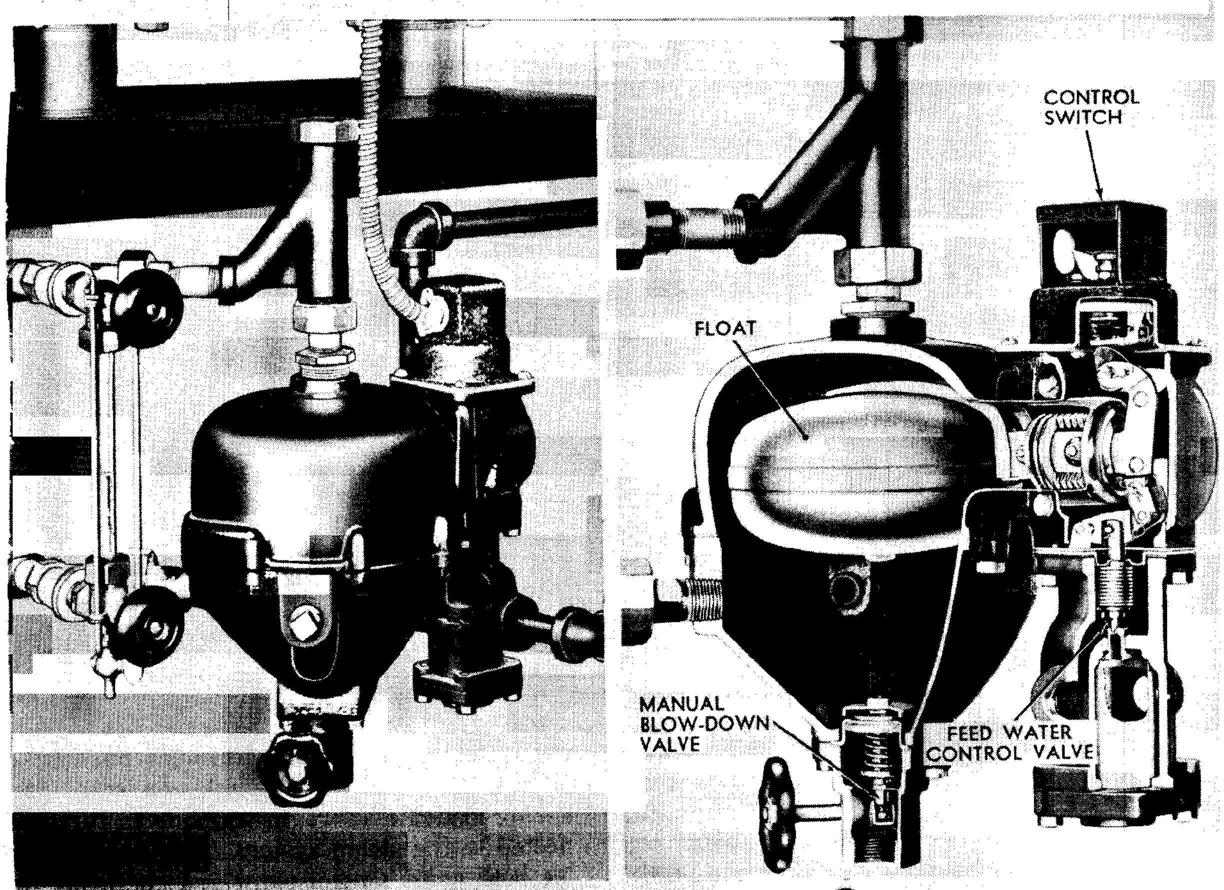


Figure 3-52. Automatic waterline regulator.

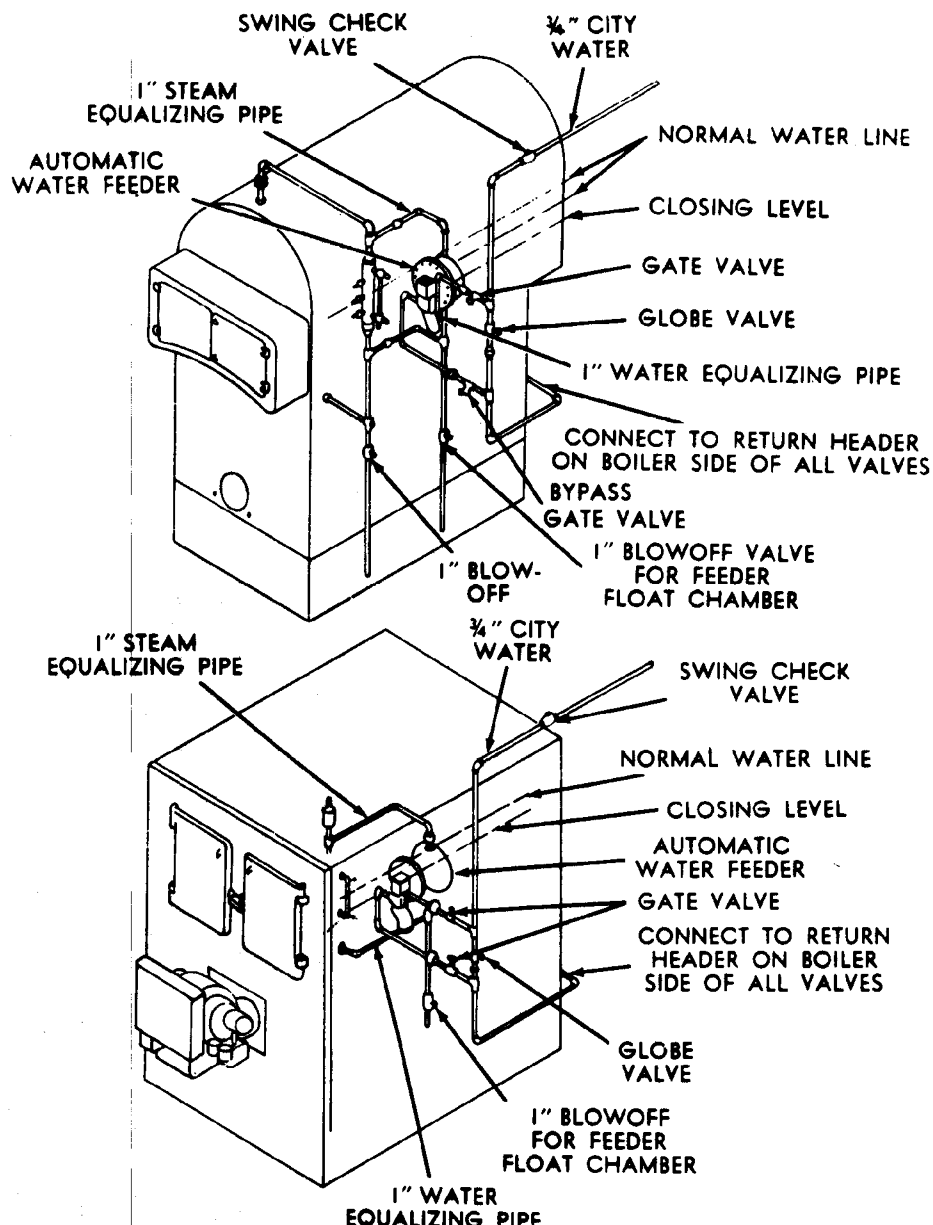


Figure 3-53. Connection of waterline regulator.

tors or exposed or concealed steam or hot water pipes or where they will receive direct rays from the sun. If tampering with thermostat setting or adjustment may be a problem, the instrument setting can be locked or the entire thermostat can be surrounded by a protecting cage.

b. Pressure Control.

(1) *Description.* Steam pressure controls report pressure changes through opening or closing of an electric switch connected to a spring-loaded diaphragm which is in turn connected to the steam system. They are adjustable both as to control point and operating differential and are available in several ranges (figs. 3-47 and 3-48).

(2) *Application.* The use of a pressure control as an operating control was discussed

in a(2) above. Pressure controls are also used in this manner when it is necessary to maintain steam pressure for other than building heating such as water heating or sterilizing.

(3) *Location.* When installing these controls, protect the bellows from direct contact with steam or vapor by the use of a gooseneck connection (fig. 3-49).

3-20. Safety Control

a. Pressure-Limit Control. Every steam boiler must be equipped with a high-pressure-limit control set several pounds above the maximum operating pressure. It is connected so that it will close the dampers on hand fired coal boilers or prevent further firing of automatically fired boilers. This limit control should be installed in addition to any operating-pressure control which may be used. The type of control used and its method of installation are identical with that discussed under paragraph 3-19*b*.

b. Relief Valves. Every steam boiler must be equipped with one or more relief or safety valve, to relieve steam pressure if all other controls fail. All approved valves are rated as to capacity, and each boiler must be equipped with sufficient safety-valve capacity to relieve steam as fast as it is generated at maximum firing rate. These valves (fig. 3-50) are spring loaded and equipped with a manual lever for checking the operation of the valve and blowing any dirt away from the seat. Safety valves are selected with consideration of the operating pressure of the system and in accordance with American Society of Mechanical Engineers (ASME) code requirements. They are installed vertically, as close to the boiler as possible, and without intervening cutoff valves (fig. 3-51). The relieving and closing pressures of safety valves are set after installation in accordance with ASME code requirements.

c. Low-Water Cutoff and Automatic Water Feed. Because safe and satisfactory operation of a steam boiler is absolutely dependent upon maintenance of the boiler waterline within reasonably close limits, steam boilers are equipped with automatic water feed and low-water cutoff or alarm devices wherever practical (figs. 3-52 and 3-53). These controls, which are usually combined in one device, consist of a float-actuated valve or switch, or combination of both, mounted outside the boiler at the desired water level. Regulators can be provided to serve some or all of the following purposes: (1) to maintain a minimum waterline by cutting in a float-actuated cold-water makeup; (2) to eliminate too high a waterline by opening a float-actuated overflow line; (3) to maintain a normal waterline by control of condensate-return pump; (4) to serve as a high or low waterline alarm by a float-actuated switch; and (5) to stop the stoker, oil burner, or gas burner if waterline falls too low. Safe operation of these devices depends upon regular maintenance. They should be cleaned once a week, or more if necessary, to prevent scale or sludge from blocking the action of the float. For a visual check on the operation of these controls, boilers must be equipped with a waterline gage glass which must also be kept clean at all times. For further information see TM 5-644.

Section IV. INSTALLATION

3-21. Location Selection

Steam heating systems are installed and maintained in accordance with the information presented in this manual, TM 5-644, TM 5-650, and TM 5-746. Boiler location is usually dictated by chimney location, as flue connections are always as short and direct as possible. Wherever there is a choice, boilers are located as centrally as possible to the areas they serve. Problems of even heat distribution are greatly simplified by shortening and equalizing the distances from the boiler to each radiator.

3-22. Adjustment and Maintenance

Steam heating systems when properly installed require little adjustment for satisfactory heat distribution. If radiators fail to heat evenly or if the system is noisy, check the steam piping for proper size slope for condensate return. Size and location of main air-vent valves should also be checked to make certain that air is being expelled from the system as evenly and rapidly as practical. If some spaces overheat because radiators are too large, radiator output can be reduced by reducing the orifice on the radiator air vent in a one-pipe system, or by throttling the steam input to the radiator by the radiator valve in a two-pipe system. Radiators on a two-pipe system can be throttled more permanently by the installation of fixed orifices in the radiator supply connections. Proper performance of steam heating systems requires regular inspection and maintenance of air-vent valves, traps, and all other combustion safety and operating controls. For detailed inforamtion see TM 5–653.